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United States Department of the Interior
Geological Survey
George Otis Smith, *Director*

◆

Water-Supply Paper 257

◆

Well-Drilling Methods

By

Isaiah Bowman

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WELL-DRILLING METHODS.

By Isaiah Bowman.

INTRODUCTION.

PURPOSE OF REPORT.

The following report on methods of well drilling deals with a subject which should interest both the geologist and the engineer, for well drilling lies in that borderland where geology and engineering meet on equal terms. The resulting dual nature of the problems involved is best illustrated by the class of men who are constantly being called into consultation in regard to them. These men are either geologists who have had experience in water-supply problems, engineers who are somewhat familiar with geology, or men who, recognizing the special nature of the problems involved, are conversant with both geology and engineering.

During the last ten years there have been many demands for a publication on well drilling, and this report is the result of an attempt to meet these demands. The need of such a report has been increased by the fact that no adequate treatment of the subject is given in any available American publication. There are several old English texts on well drilling, and a book dealing mainly with modern English methods has been published.[a] An excellent and comprehensive work has appeared on the conditions met and the methods used in the Baku oil region of Russia, on the shores of the Caspian Sea,[b] and there are a few books and reports on oil-well and gas-well construction and care. Scattered accounts of methods employed in certain localities have also appeared in engineering journals. The trade catalogues of companies manufacturing the various kinds of well-sinking machinery contain very good descriptions of their special outfits, but no publication presents a coordinated account of the various methods of well sinking and their application to wells constructed for different purposes and under different geologic conditions.

The field studies that form the basis of the present report were undertaken in connection with ground-water investigations made in the

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[a] Isler, C., Well-boring for water, brine, and oil, 1902.

[b] Thompson, A. Beeby, The oil fields of Russia, 1904; 2d ed., 1908.

eastern United States. These studies extended over a period of three years and included actual observations of well drilling in many parts of the eastern half of the country, and were supplemented by one season's observations in the South and in the Middle West.

METHOD OF TREATMENT.

The driller deals with rocks as well as with tools, and to be successful he must understand the character and attitude of the rocks as well as the manipulation of the tools. As by far the most common object of well drilling is to obtain water, oil, or gas, this report deals with the occurrence of these products and thus meets the desire among drillers for information that will enable them to select well sites with as definite an idea as possible of the rock formations that may be encountered. The report does not, however, take up the geologic relation of ore deposits and the methods of ore prospecting with drills, for such a discussion would involve the whole subject of structural and metamorphic geology and ore deposition.

After the oil and gas-bearing relations are discussed a short account of the development of well construction is given, and then the methods of drilling and boring are described in detail. The chief uses and general features of each method are discussed, the different parts of the outfit, its modifications, and its operation are described, and the more common difficulties encountered in its use are stated, together with the classes of material to which each method is best adapted.

The less familiar methods as well as those commonly used are discussed, for though the unusual methods are of restricted use and, owing to changed economic conditions, have been superseded by other methods in many localities where they were formerly much employed, they can be successfully used in new territory where the conditions are similar to those that once existed in the older fields. The presentation of these now generally obsolete methods may therefore enable drillers in the newer parts of the country or in the island possessions to meet advantageously the conditions existing in those regions. Two specific examples may be mentioned in illustration of this point. Throughout central Texas, Oklahoma, and parts of Kansas water wells are sunk by portable churn drills operated by horsepower. Horsepower is now obsolete in the East, where it has been superseded by steam, but in the Southwest, where coal is scarce and transportation rates are high, horses are plentiful and cheap and horsepower is more economical than steam. From Mississippi and Alabama many orders come to northern and eastern supply houses for well-drilling or well-boring outfits that can be operated by hand for sinking shallow water wells. Here, again, the reasons for retaining the old-style outfit are clear. In these States fuel is costly and horses are not plentiful, but labor is cheap, so that although the machine in use is primitive, it meets the conditions better than any more elaborate device.

The treatment of the separate methods is followed by a discussion of a number of special features of well construction and a few general estimates of the cost of well sinking. Though figures showing cost can be only approximate, because local conditions are important factors in their determination, they at least afford some indication of the expense of well construction or of prospect work by the ordinary methods of drilling and boring.

ACKNOWLEDGMENTS.

The preliminary discussions of rainfall, underground water, and water-bearing formations (pp. 9–21) have been compiled chiefly from a paper by M. L. Fuller.[a]

For assistance in collecting material for this report the writer is indebted to well owners, drillers, and representatives of supply companies throughout the country who have cooperated in its preparation with unfailing courtesy and good will. Individual mention is made in the body of the report of those who have given special aid in the work. Some of these men have taken great trouble and incurred considerable expense to procure data that are of great general importance though of no immediate practical benefit to themselves. At the end of the report is given a list of the supply companies that have assisted in bringing it up to date by furnishing estimates and descriptions and by giving permission to reproduce illustrations and other copyrighted material. Any failure in the report to meet the practical needs of drillers and others interested in the development of underground resources is not due to lack of interest and support on the part of those who have thus cooperated with the author.

UNDERGROUND WATERS OF THE UNITED STATES.

AMOUNT AND DISTRIBUTION OF RAINFALL.

Practically all the water encountered in well drilling is derived from rainfall. Its amount and its disposal and the conditions of its occurrence in the rocks will therefore be briefly considered.

In the eastern United States the rainfall is plentiful, the yearly average varying from 20 to nearly 70 inches. (See fig. 1.) Rain to a depth of more than 60 inches a year falls on the Mississippi Delta below New Orleans, and along the Gulf coast from near Mobile, Ala., to Tallahassee, Fla. A nearly equal amount falls in the higher mountains of western North Carolina and eastern Ten-

---

[a] Fuller, M. L., Underground waters of eastern United States: Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 18–40.

nessee, along the coast of North Carolina, and in the Adirondack and White mountains. In the Gulf and South Atlantic States the rainfall is between 50 and 60 inches a year; in the New England, Central Atlantic, and Ohio River States, between 40 and 50 inches; in the upper Mississippi and Great Lake States, between 30 and 40 inches; and in northwestern Iowa and most of Minnesota, between 20 and 30 inches.

In the western part of the United States the distribution of the rainfall is much more irregular than in the eastern part. Westward from a line drawn through the eastern part of the Dakotas, middle Nebraska, western Kansas, and central Texas the rainfall decreases to less than 20 inches yearly, all of the Great Plains region being characterized by small rainfall. In the Black Hills, the Bighorn Mountains, and the higher sections of the main chains of the Rocky Mountains the rainfall is 20 or 30 inches yearly; and in the high Sierra, the Cascades, and the Coast Ranges it is 70 inches or more, reaching a maximum of 150 inches in the Coast Ranges of Oregon. In the Great Basin region, between the Sierra Nevada and the Wasatch Mountains, the rainfall is less than in any other section of the country, in places being as low as 2 or 3 inches a year.

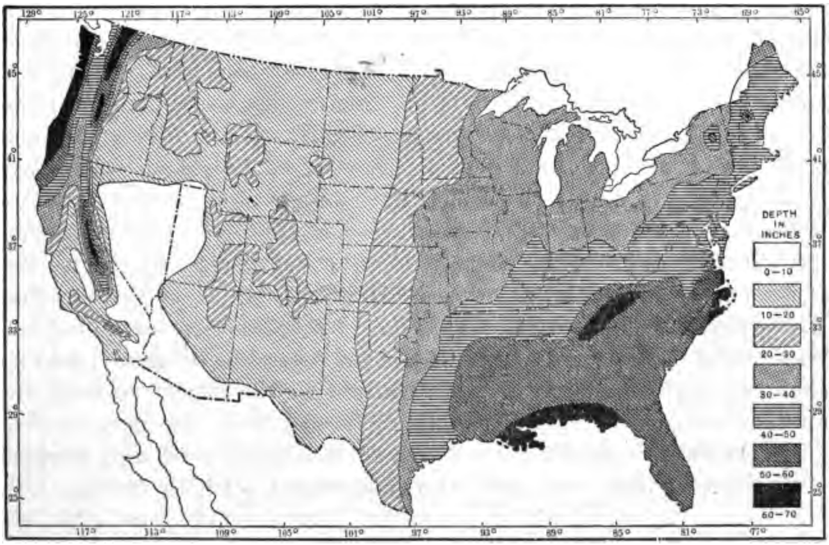

FIGURE 1.—Map showing mean annual rainfall of the United States.

DISPOSAL OF RAINFALL.

RUN-OFF.

The greater part of the precipitation on most areas is disposed of directly by run-off through surface streams. The direct run-off can sometimes be determined, but, owing to the intimate relations of stream flow to the ground supply from which streams draw much of their water, it is seldom practicable to determine the run-off for large areas. In arid regions, where the surface deposits are porous, the run-off is relatively small, but, owing to the fact that rain in these regions falls chiefly in sudden downpours, the annual run-off is not so small as would be indicated by the small annual precipitation. In humid regions and in places where the surface is composed of impervious materials the run-off is greater. Frozen, snow-covered, and ice-covered ground yield especially large flood flows. Over frozen areas nearly all the rain water may at once join the streams, whereas in some sandy regions practically all the precipitation is absorbed by the soil. In the eastern half of the country the run-off will probably not average more than 20 per cent of the rainfall. In the West, although the percentage of run-off in small areas is at times great, it is on the whole less than in the East, for much of the water that is not taken up directly is later absorbed from the streams by the dry, sandy soils.

EVAPORATION.

Owing to the great humidity of the atmosphere during storms, evaporation while rain or snow is falling is small. Snow may remain on the ground a long time, and, as a rule, is evaporated to a greater degree than rain, especially during periods of sunshine and warm winds that follow storms. The evaporation from different areas also differs greatly. From forest-covered soils it is relatively small; from open plains it is relatively large.

ABSORPTION.

AMOUNT.

The rain water that is not evaporated immediately or carried off by streams sinks into the ground. The ground receives the greater part of the rainfall, probably nearly 80 per cent in the eastern United States and 90 or 95 per cent in much of the West. Absorption by the underlying rocks takes place both directly and indirectly. Rain may fall on the surface of the rocks and be absorbed in their pores, fissures, and cavities, or it may be first absorbed by loose, unconsolidated surface deposits and afterwards carried down into the rocks, or it may be gathered into streams that flow over rock surfaces and from these gradually absorbed by the underlying rocks. The amount of rainfall that the rocks absorb indirectly is far greater than that which they absorb directly.

Water that enters sands and gravels generally moves toward the streams rather than away from them, but in regions where the rainfall is small the gravels may absorb water from the streams which rise in regions of greater rainfall.

FACTORS INFLUENCING ABSORPTION.

Structure.—The readiness with which water enters the underlying rocks is influenced largely by the structure of the rock beds or layers. In areas that are level or gently sloping the exposed areas of water-bearing beds that are not greatly inclined will be much greater than the exposed areas of beds that dip steeply and will therefore absorb a greater amount of water. (See fig. 2.)

Porosity.—The pore space between the particles that constitute a rock—that is, the porosity of the rock—may in a general way be determined by the quantity of water which the rock will absorb. This quantity differs greatly with different kinds of rock, being least in compact igneous rocks and greatest in sandstones and loose sands.

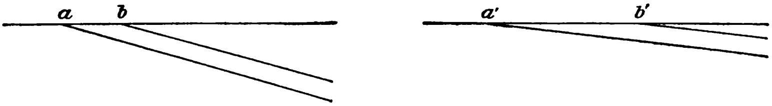

FIGURE 2.—Diagram showing relation of areas of outcrop to dip. *a b*, Outcrop of steeply dipping stratum; *a' b'*, outcrop of gently dipping stratum.

The following table shows approximately the amounts of water absorbed by sand and by some common rocks.

Absorptive capacity of rocks in quarts of water per cubic foot.[a]

Sand	10
Potsdam sandstone	2-6
Triassic sandstone	4
Trenton limestone	¼–1¼
Dolomite	1–10
Chalk	8
Granite	1/100–¼

Solution caverns.—In some regions water enters the ground in definite streams through caverns or other passages formed by the solution of limestone or other soluble rock. Water commonly enters limestone through depressions called sink holes, or "sinks," due to the falling in of the roofs or walls of caverns which have been formed by underground streams, or by the enlargement by solution of cracks or joints in the rock. These sinks maintain connection between the surface and the underground channels, water flowing into them and passing downward to become a part of the underground supply.

Faults.—Faults are displacements along fractures that cut the rock. Some faults consist of single planes, with solid walls on each side, but many of them are formed of a number of parallel fractures, very

---

[a] Water-Supply Paper U. S. Geol. Survey No. 114, 1905, p. 23.

close together, along which there has been displacement. The rock on both sides of many faults is crushed and the fragments are more or less disturbed with relation to one another. Some fractures are irregular, and the broken rock has been so moved that projecting masses come opposite one another, leaving intervening cavities into which water may penetrate.

Bedding planes.—Bedding planes, separating layers of stratified rock, may afford openings for underground water. The planes in igneous rocks along which two kinds of rock come in contact may afford similar openings. In each the movement of water is rendered easy either by the open space formed along the planes or by the contact of porous and impervious materials or by both of these causes.

Joints.—Joints are smooth fractures that cut the rock in various directions. They therefore correspond most nearly to single faults, but they differ from faults in that there has been practically no movement of the rock along them. Like faults, they present conditions that are relatively favorable to the entrance of water, especially at the intersection of two or more joints.

In the Connecticut Valley, after a rainstorm, one may see on the faces of cliffs of jointed trap rock evidences of the water-holding capacity of joints. These cliffs are darkened at the joints for hours or even for days after the rain has ceased by the escape of accumulated water, while the rest of the cliff is quickly dried under the action of the sun and wind and presents its usual appearance.

Cleavage planes.—Cleavage consists of minor fractures that cut the rock. Unlike joints, cleavage planes usually run in only one direction, and are frequently not actual fractures, but simply lines of weakness, along which the rock tends to split. Cleavage is best developed in fine-grained compact rocks, of which roofing slate is a good example. Cleavage planes do not afford as ready passage for water as do the other structures described.

Foliation and schistosity.—Foliation and schistosity are due to the presence in rock of minerals that occur in thin, plate-like crystals that lie parallel to one another. In many places water passes readily into the rock along planes formed by layers of these crystals.

AMOUNT OF UNDERGROUND WATER.

A part of the underground water which has reached the lower levels occupies spaces along bedding, fault, joint, and other planes, and a part occupies solution channels and caverns formed in soluble rock. The several kinds of fractures mentioned, although very numerous in the aggregate, nevertheless comprise only a small portion of the open space within rock. The pores between the particles that make up the rock are, on the contrary, everywhere present throughout the entire mass and constitute by far the largest part of the open space within it. The pore space thus affords the best reservoir for the storage of water.

In most places it is necessary to penetrate some distance below the earth's surface in order to reach a zone saturated with water, the actual depth depending on the amount of precipitation, the character of the rock, and the topography.

This depth is least in regions of much rainfall and greatest in arid regions; and in general it is least in valley bottoms and greatest in the higher lands. In some localities, as at springs and in marshy lands, the plane of saturation coincides with the surface, but the existence of ground water at the surface is due to exceptional conditions.

The lower limit of penetration of water depends on a number of conditions. The limit to which water will penetrate is the depth at which the weight of the overlying rock becomes so great that pores between the particles can not exist. This depth has been theoretically placed at about 6 miles. Practical experience in well drilling, however, does not approve the assumption that all rocks are saturated below a moderate depth. In the Pennsylvania and the New York oil regions, for instance, rocks that are practically destitute of water are encountered at a depth of only a few hundred feet. These rocks include coarse-grained sandstones capable of holding large amounts of water, yet as far as can be determined they are quite dry, so that it is necessary in some wells to pour in from the top the water required in drilling. In some parts of these oil fields the drill enters rocks containing salt water after passing through these water-free rocks; but very rarely is fresh water found below the dry rocks. In some places wells have been drilled several thousand feet deep without encountering water below the first few hundred feet; but, although the rocks thus penetrated are far from being saturated, they doubtless hold slight amounts of moisture. These facts show the fallacy of the popular idea that there is plenty of water if one only goes deep enough, and that great underground lakes exist.

Although the depth to which water penetrates in large quantity is much less than is frequently assumed, the ground contains, nevertheless, an enormous amount of water. Many estimates of the amount of ground water have been made, all of which take into account only the free water (that which is or might be available for pumping purposes) and do not include that which is contained in moist clays and other materials and is not readily yielded to wells. These estimates have become more and more moderate, ranging from that of Delesse, made about 1860, which showed a layer sufficient to cover the surface of the globe 7,500 feet deep, through that of Slichter (1902) which showed a similar layer 3,000 to 3,500 feet deep, and of Chamberlin and Salisbury (1904) which gave a layer of 800 to 1,600 feet thick, to that of Fuller[a] (1906), which shows that the amount of water available in the earth's crust is sufficient to form a layer over the surface of the globe a little less than 100 feet deep. This amount is equivalent to about $\frac{1}{100}$ part of the volume of oceanic water.

ARTESIAN CONDITIONS.

The requisite conditions for artesian water are fewer in number than is usually supposed, and some artesian flows are found under circumstances which are considered anomalous. The conditions for artesian flow are clearly stated by Veatch,[b] who says:

> Underground water in passing downward may go beneath a relatively impervious layer which tends to confine it and produce a hydraulic head. In this respect underground waters differ from surface waters, which are always free on one side and can not, except where artificially confined, as by closed flumes, produce analogous phenomena. This natural confinement of the ground water causes water in wells to stand above the porous layer in which it is encountered and is of vast economic importance, especially in arid regions, where the water is very deep seated and has been transferred from a region of more bountiful rainfall.
>
> In order that a well may flow it is necessary that the following conditions be satisfied:
>
> 1. There should be sufficient rainfall.
> 2. There should be relatively porous beds suitably exposed to collect and transmit the water.
> 3. There should be less porous or relatively impervious layers so placed that they may confine the water collected.
> 4. The level of the ground water at the source should be at a sufficient height above the mouth of the well to compensate for the loss of head due to resistance and leakage.
>
> The arrangement of the factors which produce a flow is by no means constant. These factors vary considerably from point to point, and relatively new combinations are to be constantly expected. Probably the commonest combination is that shown in the accompanying diagram [fig. 3]. Here the confining beds are clay

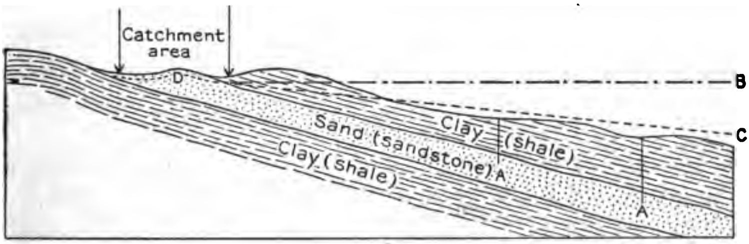

FIGURE 3.—Diagram showing ordinary conditions producing artesian wells. A, Artesian wells; B, head of water if there be no loss by resistance and leaking; C, actual head or hydraulic gradient; D, ground-water table at outcrop.

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[a] Fuller, M. L., Total amount of free water in the earth's crust: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 59–72.

[b] Veatch, A. C., and others, Underground water resources of Long Island, New York: Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 54–55.

and the porous bed is a sand which dips regularly in the direction in which the surface slopes. Water falling in the region marked "catchment area" sinks into the sands and supplies the artesian wells on lower ground.

The foregoing conditions may be taken as typical of a large class of artesian wells and are perhaps those more commonly described and understood, but flows may be obtained under several modifications of the conditions described, though they depend on the same general principles.

WATER-BEARING FORMATIONS.

GEOLOGIC CONSIDERATIONS.

Geologic knowledge has perhaps no greater practical value than in the study of the occurrence of underground water and in the selection of sites for drilled wells. In many places the selection of the location for a well is so restricted that there is practically no choice at all. Yet, though water supplies for public buildings and institutions are usually required on the premises, it may often happen that if the site had been shifted a few yards water would have been reached at much less depth; or if it had been moved down the dip of the strata a short distance flowing water would have been tapped and pumping would have been avoided.

The locating of wells is subject to so much superstition and guesswork among drillers and prospective well owners that it seems worth while to point out a few general principles that should control.

Many of the details that influence the presence of underground water can be intelligently determined only by means of an examination of the region in which the well is to be sunk and a careful analysis of observations of other wells put down in the locality. The observing well driller will furthermore take into account the surface drainage of the region, the presence or absence of forest lands which may influence the rate and amount of run-off, the existence of springs as evidence of surplus water at given points, and the depth and character of soil overlying the rock. Especially will he consider the structure of the soil cover, for it may be water-laid and therefore stratified and regular in its formation, so that an accurate and quick deduction can be made as to the depth and availability of the ground-water supplies; or it may be wind-laid and therefore less regular; or, in regions covered with material deposited by ice it may be still more irregular. All ground water, however, has a more or less intimate relation to the surface drainage and the topography.

Even after the most thorough investigation of the surface geology, however, there is always a certain degree of chance in the results of the first well drilled in a region. The variations from conditions predicted are, as a rule, small, or even insignificant, but occasionally they are great, as the projectors of the Simplon tunnel discovered when they encountered unexpected volumes of heated water. Therefore the conclusions of a competent geologist are to be considered by the well driller as a moderately safe guide in a new region, one which will enable him to determine roughly the possibility of obtaining water, the method of drilling to be employed, and the length and kind of casing that will be required. More reliable geologic inferences, however, can be drawn only after some drilling has been done in the region; so that the geologist and the driller must supplement each other.

CLASSES OF MATERIAL.

SANDS AND GRAVELS.

Beds of sand and gravel are very porous, as much as 30 per cent of the volume of some of them being made up of free space, so that saturated layers that are penetrated by wells yield copious supplies of water. This water is in most places of good quality, but in some wells it is greatly mineralized with salts derived from the more soluble rock fragments that constitute the deposits.

In passing downward through sands, especially the finer varieties, surface water may be naturally filtered so that substances with which it may have been polluted are removed. In coarse sands and in gravels the water passes downward more rapidly and the conditions are less favorable for its filtration, so that it may remain polluted. In general, however, water derived from sands and gravels that lie a considerable distance below the surface is pure.

Because of the readiness with which sands and gravels yield their water, wells that are sunk close together in them may affect one another, the deeper wells, or those which derive their supply from the sands at the lowest points, drawing the water from the shallower wells. The readiness with which the water moves is also the cause of important fluctuations in the level of the surface of the saturated zone, as the water level may fall rapidly after wet seasons. To procure permanent supplies a well should penetrate below the level to which the water surface falls in the driest season.

CLAY.

Pure clay is nearly impervious to water and contains little or none that can be utilized as a source of supply. Water is frequently reported in clay, but as a rule it comes from more or less sandy layers within a clay bed. In some places sand that approaches clay in fineness and that is sometimes mistaken for clay yields considerable amounts of water. Clay is of great importance in connection with underground water, not directly as a water-bearer, but as a confining layer to porous sands from which it prevents the water from escaping.

Because of the fineness of clay the water it contains comes into contact with a relatively large amount of mineral matter and may become mineralized, especially by lime and salt, but as a rule it is free from contamination by the organic substances that cause typhoid fever and other diseases.

When it is necessary to obtain water from clay the well should be as large as practicable and should be carried deep enough to provide ample storage capacity, for clay yields only a small amount of water, and that very slowly. Dug wells are usually most satisfactory where clay is near the surface, but should be carefully covered and protected from pollution.

TILL.

Till is a heterogeneous mixture of clay, sand, gravel, and bowlders. In texture it ranges from very pervious to impervious, according to its content of sand or of clay. In few places is it definitely bedded. Water generally occurs in it in minute, more or less tubular, channels, but occasionally is distributed through interstratified sandy beds. In the finer, more loamy phases the supply is not abundant, but the coarser portions of the material furnish water more plentifully.

In the aggregate, till yields a large amount of water, and where it is sufficiently thick it forms a most convenient and accessible source of supply, but because its material is so irregularly disposed the success of the wells varies greatly. Water is usually found in it close to the surface, but better water can be obtained by casing off these upper water-bearing beds and extending the wells to greater depth. In general, wells of large diameter, similar to those dug in clay, are most satisfactory, for the surface of the till exposed inside the well—that is, the surface from which water can enter the well—is much greater than that exposed in a bored well, and the larger wells also have greater storage capacities. Dug wells may therefore utilize small supplies which would be insufficient for bored wells.

The water of till is generally uncontaminated, because in its downward passage through the clay, of which till is in part composed, it is subjected to thorough filtration. If the water does become polluted, however, it may retain its dangerous character for a long time and for considerable distances.

Till is widely distributed over the northeastern and north-central parts of the United States in the great areas covered by glacial drift. The southern border of the glacial deposits extends from Marthas Vineyard, in Massachusetts, through Long Island and northern New Jersey, across northern Pennsylvania into the southwestern part of New York. Thence it turns southwestward across Pennsylvania and Ohio, southern Indiana, Illinois, and central Missouri, and then swings northwestward into Canada.

SANDSTONE, CONGLOMERATE, AND QUARTZITE.

Sandstone is, on the whole, the best water bearer of the solid rocks. Under the most favorable conditions it is saturated throughout its extent below the ground-water level and yields water freely wherever it is struck by the drill, although some of the fine-grained sandstones yield it less readily. Water derived from sandstone is of better average quality than that obtained from any other material except sand and gravel. It is seldom polluted, and the wells supplying it can generally be safely used if they are cased to keep out surface water. Wells obtaining water from sandstone are usually drilled, although where the sandstone is very near the surface dug wells are common.

In the Appalachian Plateau—the area comprising the bluegrass district of Kentucky, the Nashville basin of Tennessee, and the Cumberland and other plateaus of Tennessee, West Virginia, western Pennsylvania, and New York—sandstone is perhaps the chief of the water-bearing sedimentary rocks. Where sandstone beds are exposed along ravines springs issue from them, and these springs are the source of supply for a large number of the inhabitants.

Porous sandstones also underlie the great plains of the Dakotas, Kansas, and Nebraska, and yield artesian flows throughout an extensive area. Over much of the region that lies farther south they also furnish abundant underground water.

In some places conglomerate yields considerable water, although as a rule its absorptive capacity is not so great as that of sandstone, and it is not so widely distributed.

Quartzite is a metamorphosed sandstone, the spaces between the grains being filled by hard, siliceous matter. Because of this filling of the pores there is little chance for water to enter the rock, hence it is not commonly an important source of water.

Old sandstones, shales, and other sedimentary rocks that have been altered to quartzites or slates lie near the surface in the Appalachian Mountains, the Ozark and Superior highlands, and the Rocky Mountains, and on the borders of these higher lands yield some water, but generally both the occurrence and quality of such water are uncertain.

SHALE.

Shale, like clay, is a poor water bearer, but may yield water from bedding, joint, and cleavage planes, and other crevices. It is most important, however, as a confining layer to prevent the escape of water from porous sandstone that may be interbedded with it. The water in shale is reached by deep wells and is generally uncontaminated by the bacteria of disease, though it may be salty or bitter or otherwise undesirable.

LIMESTONE.

The water of limestone occurs mainly in open channels and caverns which have been formed by the solvent action of water passing along joint or bedding planes. These caverns and water channels are very irregularly distributed and their location can seldom be determined by examining the surface, but most deep wells in limestone regions encounter one or more such passages at relatively slight depth. Adjacent wells sunk in limestone, even if only a few feet apart, may obtain very different results, as a difference of a foot or two in position may mean missing a water channel. The water of limestone regions contains dissolved calcium carbonate (commonly called carbonate of lime) which makes it hard, but usually it is not otherwise heavily mineralized. It is, however, likely to be polluted owing to the fact that much of the water of the underground streams in limestone has found its way downward through sink holes and carries with it more or less surface wash.

Water-bearing limestones occur in the southern and southeastern portions of the United States and also in the Appalachian Mountains, but owing to the poor quality of the water, recourse is usually had to springs or to wells sunk in other rocks.

GRANITE, GNEISS, AND SCHIST.

Granite and gneiss are very dense and have very small pore spaces, and therefore hold but little water. Schist may contain considerable water that has penetrated along foliation planes and is held by the rock, but it gives up water very slowly and is not important as a source of supply. The joints in these rocks yield the largest amounts. Joints are most common near the surface and diminish in number and definiteness with increase in depth. For this reason most wells in crystalline rocks obtain water, if at all, within 200 or 300 feet of the surface, and it is generally useless to go deeper than 500 feet, although in some places, as at Atlanta, Ga., water supplies have been obtained from them at depths as great as 1,600 feet.

The joints in crystalline rocks usually form complex systems of intersecting planes, and polluted water may pass in a zigzag course from the surface downward along the joints until finally it reaches the well at a depth of many hundred feet.

Varieties of the older crystalline rocks outcrop or lie near the surface over the Piedmont area along the eastern front of the Appalachian Mountains, along the Sierra Nevada, and in parts of the Cascade and other ranges of the Pacific coast. In the inhabited districts in these areas some water is obtained from shallow wells sunk into the upper, decayed portion of these rocks, but where surface water is available streams and springs are used for domestic supplies.

LAKE AND STREAM DEPOSITS.

Along the northern portion of the Atlantic coastal plain there are extensive lake and stream deposits of clay, sand, and gravel, which are largely drawn upon for domestic water supply. This water is usually plentiful and good.

In the lower Mississippi Valley the fine silts of the flood-plain deposits are saturated with water a short distance below the surface and furnish abundant supplies to small wells. The chief drawback to shallow wells in this material is the unusually small mesh of the screens that are necessary to exclude the fine sand from the wells. In most places, however, a lens of coarser sand or gravel can be located, and this can be drawn on for water supply without danger of clogging the screen.

In many parts of the arid region of the western United States there are great basins or valleys which are deeply filled with sediments brought down by streams and deposited in former lakes. In some places these unconsolidated sands and silts contain water at shallow depths, and they form the chief source of supply throughout much of the Great Basin region of Utah, Nevada, southeastern Oregon, and southeastern California. In the more favorably situated of these desert valleys, notably in the Coachella Valley, in southeastern California, the deeper water of the unconsolidated deposits may be under sufficient artesian head to yield flowing wells.

In the great central valley of California and in the coastal slopes of the Pacific States there are also deep alluvial deposits that are of great importance as sources of underground water. Those of the coastal plain of southern California have been extensively tapped to obtain water for irrigation, and water is also drawn from similar deposits around Puget Sound.

Many smaller deposits of alluvial material at the bases of the western mountain ranges also yield valuable supplies of water to shallow wells.

OIL AND GAS BEARING FORMATIONS.

STRUCTURE AND CHARACTER.

Oil and gas occur under conditions that here need but brief description. As a rule they are associated with the rock structures called anticlines—upward, archlike folds of the rocks—along the flanks or in the highest portions of which oil and gas collect. Where both are present the gas overlies the oil, which in turn lies upon water-bearing beds. The presence of underlying water is usually considered necessary to the collection of oil, as because of its lesser specific gravity the oil rises above the water, is forced into the highest parts of the folds, and is held there by the overlying impervious rocks and the underlying water. Anticlinal folding, however, is not an absolutely essential feature, for it is not found in all oil fields.

Oil and gas occur almost entirely in sedimentary rocks (shales and sandstones), and their origin is very generally ascribed to the slow decomposition and distillation of organic matter. Rarely are they found to penetrate from sedimentary into igneous or plutonic rocks.

DISTRIBUTION.

Since the discovery of petroleum in commercial quantities in Pennsylvania the development of the oil fields of the United States has progressed rapidly, and the present oil and gas production of the United States is greater than that of any other country.

Oil and gas are found in the Appalachian field at depths ranging from 400 to 3,000 feet, and are drawn from several horizons. The reservoirs are made up of layers of porous sandstone which are separated by shaly beds. Within the sandstone layers the oil has accumulated in "pools," presumably under the influence of gravity.

The many beds of sandstone form a series of rocks about 2,000 feet thick, deposited during the Devonian and Carboniferous periods of geologic time. Near the western margin of the Appalachian field the oil and gas bearing beds dip gently southward or southeastward, so that the oil-bearing sandstones are carried farther beneath the surface. In West Virginia oil is obtained from wells between 3,000 and 4,000 feet deep.

In that part of the Pennsylvania field which lies within the Appalachian zone of folding, gas and oil are in places found only within the area of the folds. As the gas, on account of its lower specific gravity, lies above the oil, in some localities it is possible to drill wells on the flanks of a fold and reach the oil directly without meeting the gas.

In western Ohio and Indiana oil is produced from the Trenton limestone, a rock different from that found in the Pennsylvania field. The original productive Ohio field has been developed until it now extends across Indiana and into Illinois. The wells of this field range in depth from 100 to 1,400 feet. In eastern Illinois oil is obtained at depths ranging from 400 to 600 feet from soft and very porous limestone lying beneath beds of shale.

In the oil fields of southeastern Kansas and adjacent parts of Oklahoma the oil and gas reservoirs are in sandstone interbedded with shale.[a] As the outcrops of some of the sandstone beds may be traced into shale, and as the records of wells short distances apart differ greatly, it seems probable that the sandstone beds form lenses

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[a] Adams, George I., and others, Economic geology of the Iola quadrangle, Kansas; Bull. U. S. Geol. Survey No. 238, 1904, p. 25.

whose position and extent can not be predicted, except within wide limits. The beds also vary exceedingly in their content of oil and gas. The depth of the productive beds increases southward, being 400 to 700 feet in Kansas and more than 1,000 feet in the Osage and Cherokee Nations, Oklahoma.

The Gulf oil fields, which were opened in 1891 by the great Lucas gusher at Beaumont, Tex., and have been extended into a number of other localities in Texas and in Louisiana, are peculiar in that the oil and gas occur chiefly in unconsolidated sands that lie between capping layers of clay, though they are found also in this field in sandstone and in porous limestone. The petroleum at Beaumont is produced from a loose, honey-combed rock, lying 1,000 to 1,200 feet below the surface.

In California oil is found in friable sandstone and shale which are of much more recent geologic age than the productive beds of the eastern fields. Some wells reach depths of 4,000 feet or more. On account of the structure and location of the producing beds some of the wells near the coast are sunk through the shallow water off shore, and near Santa Barbara the oil derricks are erected on long piers and built out into the surf.

In Alaska petroleum fields are being explored on the west shore of Cook Inlet, at Cold Bay on the Alaska Peninsula, and near Controller Bay. The oil in these fields is found in sandy shale whose history is involved with that of overlying or intrusive beds. The structure is complex and developments are yet too meager to permit accurate determination of either the extent or character of the productive beds.

Oil in small quantities is found in several States outside the great fields, notably in Michigan, Colorado, Utah, and Wyoming. In Wyoming the indications give promise of the future production of large quantities of petroleum.

HISTORY OF WELL DRILLING.

ASIA.

In the dry regions of Asia the climate, the universal scarcity of water, the locally dense population, and the dominance of agriculture resulted in an early development of the art of constructing wells. It is not surprising that in China, a country prolific in inventions that are in modern use, there should have been devised, centuries ago, for well drilling, a churn drill which in principle is like the churn drill used to-day. It is also to the early Chinese engineers that we are indebted for one of the few known methods of sinking wells through loose soil and quicksand to great depths; that is, by constructing a curb of stone or brick, which settles as the excavation is deepened and thereby reduces the pressure of the surrounding material. The ancient writings of the Chinese contain occasional references to well-drilling machines, and to the Chinese also belongs the credit of reducing well drilling to a science. The Chinese, however, though led, naturally enough, to the invention of means of well drilling, especially in the more arid parts of their country, on the boundaries of the great desert of Gobi, reached only a very primitive stage in the mechanical part of the work, and they have made slight improvement in their machinery during the last century, which has witnessed such remarkable mechanical development in the United States.

In western China, near the borders of Thibet, a method of drilling for petroleum in use at the present day illustrates the primitive though scientific manner of well construction in that country. The drilling tool is of the free-falling kind, a hard-wood rod or lifter having an iron cap at each end serving as the hammer or maul. This is fastened to the top of an iron link and falls on the chisel or bit attached to the bottom of the link. (This device is the earliest form of the Canadian pole-tool apparatus used in this country, but as employed in America the wooden rods are used not as a maul but merely as a lifter.) The wear on the parts of the string of tools thus coming into violent contact is very great and necessitates their frequent renewal. The tools are lifted and dropped by means of a windlass having an automatic release. The drill has a narrow horizontal cutting edge by which the rock is spalled off and pounded into bits which may be removed with a sand bucket. The cable is made of twisted strands of rattan. With this outfit a great expenditure of time and labor may be required to produce meager results, and yet by its use wells have been drilled to a depth of 3,600 feet.

EUROPE.

The science of deep-well drilling received great impetus through experience gained in drilling the Passy well of Paris, completed in 1857, which was curbed to a depth of 1,923 feet. Its diameter was 2⅓ feet and it delivered 5,588,000 gallons of water daily to a height of 54 feet above the surface. Even more remarkable than this is the mammoth well at La Chapelle, which has a diameter of 5½ feet and extends to a depth of more than 1,000 feet. The drill used in constructing this well weighed 4 tons and was operated by a powerful steam engine that caused it to strike 20 blows a minute.

The artesian well at Grenelle, near Paris, completed in 1841, was for many years the deepest well in the world. The history of the seven years of incessant labor expended in its construction has been equalled in interest by that of very few other engineering enterprises.

It was in drilling this well that workmen first learned the requirements of deep drilling and first exercised their ingenuity in recovering broken parts of the drill and rods. A final depth of 1,798 feet was reached, drilling being stopped in a large cavity from which water having a temperature of 82° F. rose with great force to the surface, forming a large flowing artesian well—" a parabolic fountain " many feet in height.

The successful completion of these deep wells in France was followed by deep borings in England and Germany. Many of these were of great dimensions and for the first time gave the geologist an idea of the underground structure of the rocks, nearly every scientific society having investigated the drilling operations from one or another point of view.

UNITED STATES.

EARLY DRILLING.

Drilled and bored wells for water supply have largely superseded dug wells in many parts of the United States, because water obtained from the deeper sources that are tapped by drilled wells is less likely to be contaminated than that obtained near the surface, and the supply of these deeper wells is also usually more constant than that of shallow dug wells.

The methods of drilling water wells have been greatly improved during recent years by experience gained in sinking to great depths for oil and gas, such drilling having resulted in the development of smaller and more efficient tools.

Contemporaneous with the development of the art of deep boring in Europe, deep wells were first put down in the United States at Charleston, S. C., at Louisville, Ky., and at St. Louis, Mo. In the Pennsylvania oil fields wells 2,000 to 4,000 feet deep were drilled, the first deep well in the celebrated Oil Creek region, according to a published account of the early development of the fields,[a] having been drilled by Jonathan Watson in 1866 to a depth of 2,130 feet. With the discovery of oil the well-drilling business became continuous and profitable and soon attracted the attention of engineers whose ingenuity was taxed to the utmost by its obstacles and mishaps. At present it engages the interest of some of the most expert engineers in the country, for, with the extension of artesian-water development to nearly all parts of the world, drillers have encountered nearly every variety of geologic formation, and therefore nearly every kind of difficulty and mishap.

Tubular wells lined with iron pipe or casing superseded wells of larger diameter lined with wooden curbing or conductor pipe. In

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[a] McLaurin. J. J., Sketches in crude oil.

the central and western States tubular wells were not commonly used until 1875, but along the Atlantic coast they were drilled much earlier. As early as 1849 tubular wells were drilled with machinery and tools designed by Jesse N. Bolles and a Mr. Knight.

DRIVEN WELLS.

In localities where a pointed pipe can be driven easily to the water level many wells known as "drive" or "driven" wells were put down between 1865 and 1885, and a few such wells are still sunk. Some of these wells are made by pointing the end of a piece of iron pipe, drilling small holes near the pointed part, and driving this pipe into the earth with a sledge or drop hammer. Other sections of pipe are screwed on as the well is driven deeper. In some wells pointed screens made in various ways are attached to the bottom of the pipe thus driven. These screens prevent coarse sand from entering the pipe and wearing out the pipe valves, but many wells of this kind are short lived, and in some localities tubular wells of larger diameter, made by other methods, have taken their place.

Driven wells can not be put down in rock and many difficulties are met in sinking them. In order that they may be successful, it is necessary that the perforated end of the pipe be driven into a good water-bearing stratum in sand or gravel within 30 feet of the surface and there stopped. A patent was granted on the drive well to a Mr. Green after the civil war, but drive wells had been put down as early as 1861.

WELL AUGERS.

The method of boring wells by turning an auger into the earth was in common use throughout the country between 1865 and 1885 and is still employed in some sections. One of the first augers used for this purpose was made by J. J. W. Adams in Virginia in 1855 and is now in the possession of George D. Loomis, of Tiffin, Ohio, from whom many historical data were obtained.

Well augers, ranging in diameter from 2 to 4 inches, were much used through the Central and Western States during their settlement, and in some parts of the country they are still used, though in most places the open bored well, lined with wooden plank or with sewer pipe, has been superseded by the tubular well made by sinking a wrought-iron pipe into the earth.

JETTING METHOD.

A jetting outfit for use in sinking wells in unconsolidated deposits was built in 1884 by W. C. Wells, who did much to demonstrate its utility. In using this device the material is loosened by a strong current of water directed through a suitable nozzle or bit and is carried to the surface and thus removed by the return stream of water. Where it can be used, it is a very rapid, efficient, and cheap means of sinking wells.

SELF-CLEANING METHOD.

Machinery and tools for drilling tubular wells by what is now known as the "self-cleaning" method were constructed and used in 1857 or shortly before by Jesse N. Bolles. This method is often called "hydraulic," but the material is loosened and broken up by the percussion of a drill bit. Water, however, provides continuous self-cleaning of the hole, for by the action of the drill the loosened material is pumped up through the hollow drill rods and delivered at the surface.

Following Mr. Bolles in the use of tools of this kind came Jesse Button, a well driller and inventor. Soon after the discovery of oil in northwestern Pennsylvania Mr. Button did much drilling with a machine especially constructed for the use of the self-cleaning tools, and aided greatly in making this method of drilling efficient.

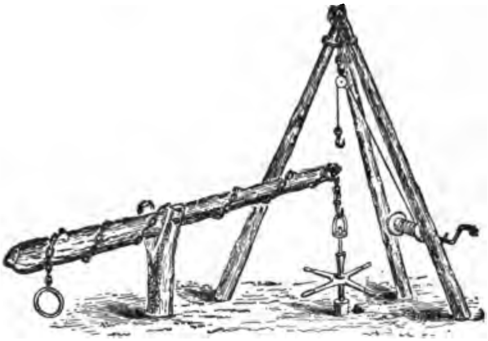

FIGURE. 4.—Spring-pole drilling outfit.

SPRING-POLE OR CHURN DRILL.

The first churn drill employed in the United States was a crudely constructed device (fig. 4) consisting of a small tree or spring pole, sufficiently strong to bear the weight of rope and drill, supported in a forked upright and securely fastened down at the larger end or weighted so as to counterbalance the drill. The pole was inclined over the hole at an angle of 15° to 30° or more from the horizontal, so that the tools could be raised and lowered in the well. The tools, which were generally made by local blacksmiths, consisted of solid wooden rods, seven-eighths inch to 1½ inches in diameter, fitted with box-and-pin joints and attached to the spring pole by a rope or chain. The cutting instrument was a steel chisel or drill welded to an iron stem a few feet long and attached to the lower end of the line of rods. Cross handles were bolted to the rods, which were supported by a swivel, and by these the drill was slowly turned during the drilling. The derrick consisted of three timbers, 20 to 30 feet or more in height, bolted together at the top; the joint was strengthened by an iron circle slipped over the timbers.

The machine was operated by two to four men, who by their weight brought the pole down quickly, so that the drill would strike a blow on the bottom of the hole. It was then lifted again by the spring of the pole. When it became necessary to pump out the accumulated drillings the tools were raised by means of a rope passed through a pulley at the head of the derrick and carried to a windlass supported on a crank shaft between two of the legs. After the hole had been cleaned, the tools were lowered by the same device. In raising the drill the different sections were unscrewed piece by piece as they came up, and they were screwed together again when the drill was lowered. A clip on the end of the rope from the windlass could be inserted in the swivel at the upper end of the string of tools, thus enabling the driller to suspend the tools temporarily when the deepening of the hole necessitated lengthening the rope or chain fastened to the spring pole. The sand pump was a long tube, 3 inches in diameter, with a hinged bottom opening inward and a piston valve working on a sliding rod, somewhat in the manner of a syringe. It was lowered to the bottom, and when the poles, which were attached to the sliding rod of the pump, were raised quickly the drillings were sucked into the pump by the sliding valve, retained by the bottom valve, and thus pumped out.

Sometimes the tools were operated by a number of men perched on a scaffold built about the well. The spring of the pole would lift the tools for the blow and the weight of the men bring them down. The work was extremely laborious, the speed attained being about 2 feet a day for each man stationed on the scaffold. The men had to rest every few minutes, and if it was desired to drill continuously it was necessary to supply double sets of men, who relieved each other after a few minutes' work. The method was often called " kicking down a well," and was employed in sinking hundred of shallow wells. It afforded men of limited means a way of obtaining a water supply, but was inadequate for deep-well drilling, and has become nearly obsolete. In drilling hard material progress was extremely slow; the force of the blow decreased as soon as a few inches had been drilled, for the drill must recut the drillings, so that the tools had to be hoisted out and the hole sand-pumped frequently.

The wells sunk by this process were as a rule not more than 4 inches in diameter and were comparatively shallow, for their depth was determined by the elasticity or counterweight of the pole and the ability of the operators to raise the tools out of the well when it became necessary to remove the drillings. However, some of them exceeded 300 feet in depth.

STANDARD METHOD.

The sinking of deep water wells and of deep borings for gas and oil made necessary the use of heavier tools, differing from those of the spring-pole outfit. The first step in the evolution of the spring pole into the standard method was the substitution of horse power for manual labor in working the tools. The next improvement was the replacement of the spring pole by the walking beam, whose motion depends not on elasticity but on power transmitted from an engine through a jack wheel and crank shaft. The first oil well drilled by steam power was put down opposite Tidioute, Pa., in 1860.

The most important implements of modern drilling are the "jars," which were long ago invented by William Morris. They consist of two linked pieces of steel of good quality, having an endwise motion, or slack, of 6 to 9 inches. They enable the delivery of a quick, hard, upward blow, which jars the tools free when the drill is working in caving or creviced material. For "fishing" for lost tools they are made longer to enable a harder blow to be delivered. Their invention made possible the drilling of much deeper holes than had before been attempted, for the driller knew that if the tools became stuck he need not depend on mere strength of rope in withdrawing them. A quick upward stroke with good, heavy, well-made jars will exert a greater force on the drill than a steady pull of several tons. It is reported that George Smith, of Rouseville, forged the first steel-lined jars in 1866, for H. Leo Nelson,[a] who also in that year adopted the "Pleasantville rig," discarding the "grasshopper." In the former the walking beam is fastened in the center to the "samson post," with one end attached to the rods in the well and the other to the band-wheel crank.

Many improvements on pumping rigs, drilling tools, and gas rigs were patented by George Koch, of East Sandy, Pa. A line to control the engine from the derrick was first used by Samuel Taft, in 1867, in drilling a well near McClintockville; and a device to regulate the motion of the engine by means of a rod from the derrick attached to the throttle valve of the engine was first used by Henry Webber, who drilled a 600-foot well near Smoky City in 1863. Webber also, perhaps for the first time, dressed the tools in a forge under the derrick.

To exclude surface water a leather "seed bag," filled with flaxseed, was tied firmly around the pump tubing and let down to the proper depth. In a few hours the seed swelled and filled the space between the tubing and the wall of the well and rendered it impervious to the passage of water.

Drilling "wet holes" was slow and uncertain, as the tools were likely to break, and whether or not a well would be successful could not be known until the pump exhausted the water; but more than 5,000 wells were sunk with the rude appliances in use up to 1868,

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[a] McLaurin, J. J., Sketches in crude oil.

before the water was shut out by inserting a larger pipe—a casing—which was usually carried to the top of the first sand. The use of casing was the greatest improvement ever devised in drilling for oil, and holes can now be sunk safely and rapidly to a depth of 5,000 feet.

HYDRAULIC ROTARY METHOD.

Although rotary methods of drilling had been used for a number of years previous to the opening of the Spindle Top oil field in Texas, the remarkable success of the hydraulic rotary drill in that field in 1901 gave great impetus to its improvement and its more general use. Its work is accomplished by means of a cutting shoe on the bottom of the casing, the whole string of casing being rotated by a suitable device. As fast as the material is loosened it is carried to the surface by a powerful water current that is forced down the inside of the pipe to the cutting shoe and thence escapes upward between the casing and wall of the hole. In the early days of rotary drilling a second casing was sunk closely following the cutting shoe, but about 1890 it was found that thick mud used with the drill water puddled and plastered up the walls of the hole and was nearly as efficient as second casing.

The method is adapted for use only in unconsolidated materials and in soft friable rocks with small crevices and pores which can be sufficiently plastered with mud to prevent too great a loss of drill water.

CORE DRILLS.

In drilling prospect holes for coal or for metallic or other deposits, or to determine the suitability of the underlying formations for bridge or other structural foundations, it is very desirable to obtain intact samples of the materials penetrated. Core drills are extensively used for this purpose, and they have been developed to a high degree of efficiency. As in the hydraulic rotary method, core drilling is accomplished by an annular shoe or bit set on the lower end of a string of hollow rods; but core drills are adapted to penetrating even the hardest rock, and instead of grinding all the material to a slush or mud, they remove the central part of the hole as a solid core.

Though core drills are seldom used directly for drilling water or oil wells, adaptations of the core-drill principle are sometimes used with well-drilling outfits. (See pp. 78–88.)

DISTRIBUTION OF DRILLED WELLS.

Drilled wells are in use in most parts of the world reached by ordinary trade routes and even in areas beyond the main lines of travel. In the United States they are most common in localities where flowing artesian water is to be reached at considerable depths, as in North and South Dakota, the Atlantic coastal plain, and southern California; in areas where relatively deep wells are required for pure but nonflowing water, as in nearly all of the eastern States; and in localities where oil and gas exist, as in Pennsylvania, West Virginia, Ohio, Indiana, Texas, Oklahoma, Colorado, Wyoming, and California. In South America they are used in developing the water resources of desert Peru and Chile, from Callao to Valparaiso, where artesian wells furnish some of the municipal and agricultural water supplies. In Siberia portable drilling rigs have been taken to the frozen flood plains of the northern rivers for gold prospecting. By the enterprise of American supply houses and drilling firms portable outfits have been taken to the arid portions of Greece, Italy, and Spain, to China and Japan, to the oil districts of Sumatra and Rangoon, to the deserts of Algeria and Egypt, to Australia, and to nearly every port of call in South Africa. In the country last named well drilling is encouraged and aided by the Cape government in utilizing underground water supplies for stock and for agricultural industries. The cost of the wells is so great that the landowner is unable to bear it alone, and the government therefore assists him by supplying machinery, material, and skilled labor, while the farmer furnishes transportation and Kaffir labor.[a] Since the value of a farm is very greatly increased by an ample water supply, the government of late has required the farmer to pay a much greater share of the cost of sinking a well.

In order to show the wide distribution of deep wells and the great depths to which they have been sunk the following list of 30 deep borings in various parts of the world has been compiled. There are, of course, many other borings that compare favorably with these in depth, but those listed are illustrative.

List of deep-well borings.

[Data collected by B. L. Johnson.]

Location.	Depth.	Diameter.	Object.	Remarks.
	Feet.	*Inches.*		
East of Rybnick, Upper Silesia, Germany.	6,572	3.6 to 2.7	Coal......	Cost $18,241. Completed Aug., 1893, after 1½ years' work. Deepest bore in the world.
Schladeback, near Leipsic, Germany.	5,735	11 to 1.3	Coal......	Cost $53,076. Completed about 1893. Average daily rate of drilling, 4½ feet.
Knurow, Upper Silesia......	4,173	192 to 13	....	
Springs, 25 miles east of Johannesburg, South Africa.	5,582	2 to 1⅜	....	Completed 1905, after 9 months' work. Diamond drill hole.
Dornkloof, 16 miles east of Randfontein, South Africa.	5,560	2 to 1⅜	....	Completed December, 1904, after 14 months' actual work. Diamond drill hole.
Randfontein, South Africa...	5,002	....	....	Diamond drill hole.
Turfontein Estates, Johannesburg, South Africa.	4,845	....	....	Do.

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[a] Ritso, Bernard W., The artesian wells of the Cape Colony: Rept. South African Assoc. Adv. Sci., vol. 1, 1893, pp. 1–21.

List of deep-well borings—Continued.

Location.	Depth.	Diameter.	Object.	Remarks.
	Feet.	*Inches.*		
Near Boksberg on the Rand, South Africa.	4,800	....	....	
Clerksberg district, South Africa.	4,500	....	....	
In the Vlakfontein district, South Africa.	4,003	....	....	
In the Black Reed series, 12 miles south of the Main Reef series on the Rand.	4,500	....	....	Diamond drill hole.
2½ miles west of West Elizabeth, Pa.	5,575	10 to 6¼	Oil........	Cost $40,000. Deepest well drilled with a cable; deepest well in the United States; third deepest well in the world.
In Aleppo Township, Greene County, Pa.	5,322	13 to 6⅝	Gas.......	Abandoned July, 1905.
Pittsburg, Pa................	4,618	....	Oil or gas..	
4 miles southeast of Wheeling, W. Va.	4,500	4⅞	...do......	
In the city of Erie, Pa........	4,460	....	...do......	Abandoned 1889.
Irwin, Westmoreland County, Pa.	4,380	....	...do......	
Buchanan well, 6½ miles south of Burgettstown, Pa.	4,303	....	...do......	
Northampton, Mass..........	4,022	....	Water.....	
New Haven Conn............	4,000	8	...do......	
Renovo, Pa.................	4,000	....	Oil........	
Bimerah Run, Queensland...	5,045	....	Water.....	Flow, 70,000 gallons a day.
Elderslie, No. 2, Queensland.	4,523	....	...do......	Flow, 1,600,000 gallons a day; temperature 202° F.
Bimerah, Queensland........	4,860	....	....	
Glenariffe, Queensland.......	4,140	....	....	
Warbreccan, Queensland.....	4,125	....	....	
Winton, Queensland.........	4,010	....	....	
Darr River Downs, No. 4, Queensland.	4,000	....	....	
Dolgelly bore, New South Wales.	4,086	....	...do......	Flow, 745,200 gallons a day.
One well in state of South Australia.	4,420	....	...do......	Flow, 600,000 gallons a day.

METHODS OF WELL DRILLING.

CLASSIFICATION.

Modern well-drilling methods may be grouped into three general classes—percussion, hydraulic, and abrasion methods.

The percussion outfits use a heavy drill bar or other tool, with suitable apparatus for lifting it and allowing it to drop, to pound the rock into fragments small enough to be readily removed from the hole. The percussion principle is utilized in the standard, portable, pole-tool, self-cleaning, and California methods, whose outfits are recognized as distinct but differ in their arrangements for handling the tools rather than in the operation of drilling. The California method belongs in this class, for though its successful use depends on a plentiful supply of water, it involves drilling by percussion.

The hydraulic outfits use water under pressure to loosen the material and bring it to the surface. The chief method in which water plays an active part in drilling—the hydraulic rotary method—has been developed mainly within the last ten years as a result of the discovery of oil in Texas in unconsolidated materials, for penetrating which the hydraulic rotary drill is especially adapted. In the jetting method used for sinking water wells in unconsolidated deposits water under pressure plays an even more important part than it does in the hydraulic rotary method, for the water jet receives little aid from the drill in loosening the material to be removed.

In methods involving abrasion the rock is worn and chipped off by rotating upon it a shoe or bit armed with some harder material. The abrasion principle is employed by three types of drills, which differ chiefly in the abrasive with which the bit is armed and are known as the diamond, calyx, and the chilled shot drills.

Several methods, including boring, punching, and driving, as well as digging, which do not come within the above classification, are employed to obtain shallow water supplies.

In many wells a single method is not employed throughout the entire work, and in some wells modifications of several methods are successively used. Though percussion tools are usually employed in drilling by any of the percussion methods, the shape of the bit used and the means of removing the drillings may be changed at different stages of progress. In the hydraulic rotary outfit a percussion drill may be substituted for the cutting shoe in penetrating hard strata, and for this purpose chilled shot, or adamantine, is also occasionally used with a suitable revolving shoe. Combinations of the hydraulic rotary and the jetting methods are also employed when penetrating alternate beds of clay and gravel. In the abrasive methods it is often found advantageous in passing through hard or tough material to replace the usual bit by one operated by percussion.

Abrasive or core drills are seldom exclusively employed for well sinking, their particular field of usefulness being in boring prospect holes for ore deposits or for other exploration work.

The terminology employed by well drillers throughout the country is fairly uniform. This uniformity has been brought about through the uniformity of the terms used in catalogues of supply houses and through the migration of drillers from the oil fields of Pennsylvania and West Virginia to other parts of the country. One of the major terms that may be mentioned is the word "rig." Among standard drillers this is usually applied only to the derrick, wheels, and reels, the word "outfit" being used to include the rig, power machinery, tools, and accessories. Those using portable drilling machines, however, apply the term "rig" to the complete machine.

SELECTION OF OUTFIT.

The proper selection of a drilling outfit requires the careful consideration of many factors, chief among which are the location and purpose of the well and the geologic structure of the rocks to be penetrated. In many localities, for example, small tubular wells, ranging in diameter from 2 to 4 inches and in depth from 50 to 200 feet, will provide satisfactory water supplies; in other localities such wells are not satisfactory and wells of larger diameter are required. The advantage of knowing the kind of outfit to select can readily be understood.

The preference of the driller must also receive consideration. An inexperienced man may quickly be taught to manipulate and use to advantage a new-style rig which a so-called experienced man, strongly prejudiced in favor of the rig with which he is acquainted can not be induced to use carefully and intelligently. This personal factor the well owner or contractor can not ignore; but the man who condemns other well-drilling methods simply because he has found satisfactory in certain localities the one or two methods with which he is acquainted must be set down as an inexperienced or an unintelligent driller.

It must be borne in mind that no one method of drilling is best under all conditions. No one method can even be said to be best under most conditions. Different methods are adapted to different localities; each style of outfit has advantages and disadvantages which must be considered before drilling is begun. The auger, elsewhere obsolete, is still used in many localities, as it is adapted to drilling shallow wells in places where a larger and more expensive rig can not be profitably employed.

STANDARD METHOD.

CHARACTER AND USES.

The largest and deepest wells put down are those sunk to obtain oil, and the heavy standard outfit, now so extensively used, acquired its essential characteristics in the development of the oil industry in Pennsylvania. In overcoming the difficulties encountered in drilling deep holes the tools have been enlarged and the several parts of the outfit have been modified and improved until the size and weight of the tools and the ease with which they are handled surprise those unfamiliar with this class of machinery.

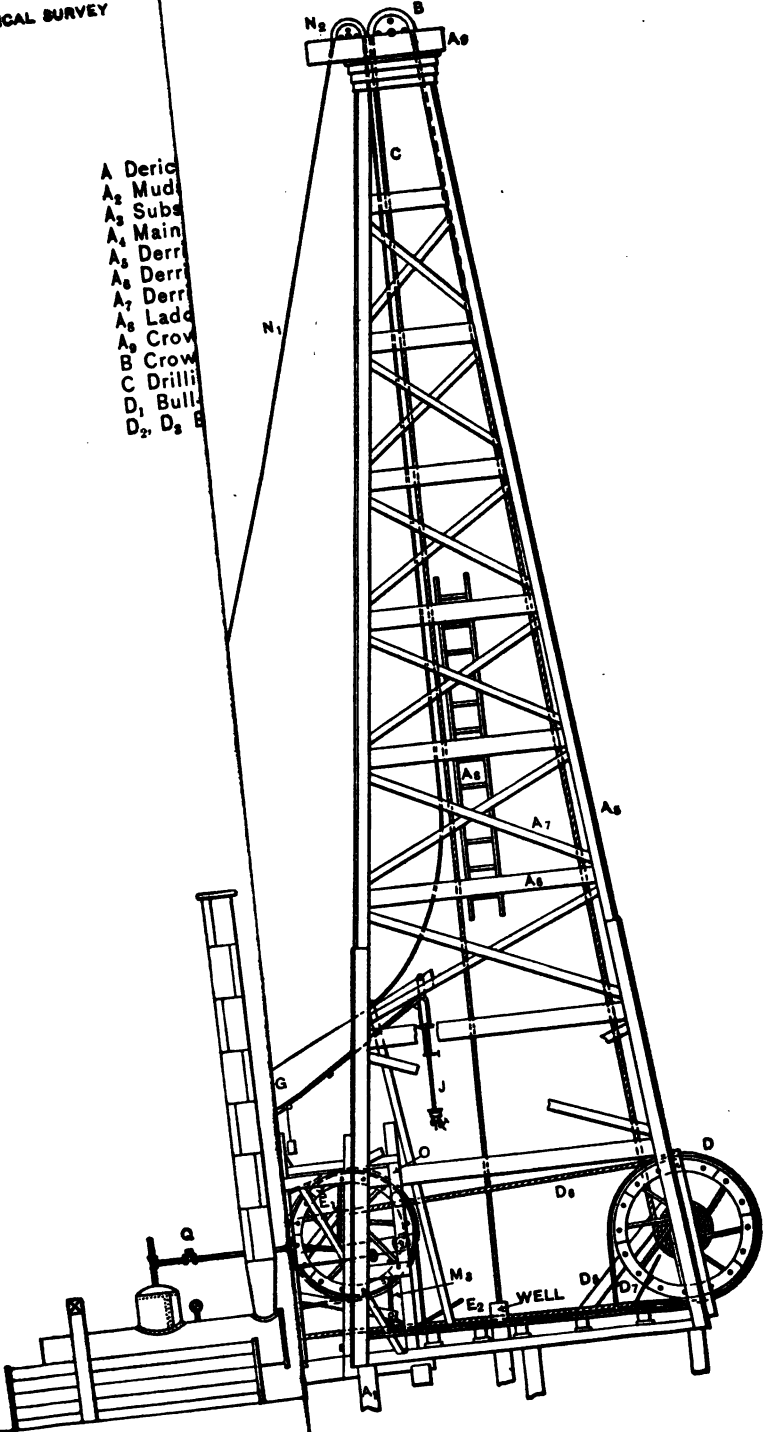
Standard outfits differ little in essential features, but hardly two can be found alike in every detail; the slight variations that exist are due not to some fancy or whim of the driller, but to the need for adapting the outfit to special conditions.

OUTFIT.

RIG.

The most noticeable part of a standard outfit is the derrick, a pyramidal framework, 30 to 90 feet high, erected over the well. In

A Deric
A_2 Mud
A_3 Subs
A_4 Main
A_5 Derri
A_6 Derri
A_7 Derr
A_8 Ladd
A_9 Crow
B Crow
C Drilli
D_1 Bull-
D_2, D_3 B



summer the derrick is usually left open except on one side, which is boarded in to form a shed for storing tools and workmen's clothes and to protect the forge—a part of the outfit that is in more or less constant use. In winter the lower part of the derrick is temporarily closed to protect the workmen. In a new territory drillers sometimes close the derrick, even in summer, to keep the results of the drilling secret.

The derrick (Pl. I) consists of four legs, steadied by girts and braces and surmounted by a crown block. In this block is set the crown pulley over which the drilling cable passes. A ladder extending up one side of the derrick provides access to the crown block. The weight of the derrick rests on foundation posts, which are set deep in the ground to render the structure firm.

At one side of the derrick are the bull wheels. This part of the rig consists of a reel, on which the drilling cable is wound, at each end of which is a wheel, usually built up of wooden arms and segments, fastened together with wooden pins. These parts are known to the trade as arms, cants, and handles. The whole is set firmly into the bull-wheel posts and strengthened by the bull-wheel post brace. The wheel at the farther end of the reel in the illustration (Pl. I, D_3) is grooved to receive the bull rope, which acts as a belt to operate the reel. The brake by which the reel is controlled passes over the near wheel of the illustration and is controlled by a lever. In the early rigs this brake consisted of rope or a piece of old rubber belting. When the tools were lowered the rope would burn and smoke, and the rubber would emit a very disagreeable odor. In present rigs an iron brake band is used.

In the California style of standard rig a second reel, known as the calf wheel, is placed on the side of the derrick opposite the bull wheels. It carries a cable that is used in lowering and in pulling casing. It is claimed that in deep drilling it saves much time as it obviates the necessity of disconnecting the tools from the drilling cable for these operations.

Opposite the bull wheels is the samson post, usually about 14 feet long. This post is strongly braced and supports the walking beam. The derrick end of this beam is directly over the well and carries the temper screw to which the tools are fastened and by which they are fed downward. The other end of the beam carries a pitman, which is connected with the crank of the jack or band wheel by a wrist pin. This band wheel is supported on jack posts and transmits power to the several parts of the rig—to the walking beam by means of crank and pitman, and to the bull wheels through the tug wheel and bull rope. In the California rig the calf wheel is also operated by the band wheel through a second tug wheel and rope belt. The operation of the calf wheel is usually controlled by a lever and clutch, and the bull wheels are usually thrown in or out of gear by putting on or removing the bull rope.

The sand reel is just behind the band wheel and is operated by the latter through a friction pulley. This reel is mounted on a knuckle post and is controlled from within the derrick by means of the sand-line pulley, and, as its name indicates, it is used in handling the sand bucket or bailer.

The part of the rig that extends beyond the derrick rests on mud sills, which are usually sunk in trenches and have gains cut in them to receive the subsills and main sill, and the whole foundation is carefully leveled up and firmly keyed together.

The headache post, also called the life-preserver, is a comparatively recent improvement. As its name implies, its purpose is to save the driller from injury to the head if the wrist pin breaks or the pitman is thrown out of adjustment while drilling, as it prevents the derrick end of the walking beam from dropping and injuring anyone who may be beneath it. This post is usually a piece of heavy timber set on the main sill directly under the walking beam, so that in case of accident the walking beam can fall only a few inches. It is also useful when repairs are necessary to the pitman or the band wheel and crank, for a block may then be placed between the headache post and the walking beam, and the pitman relieved of its weight and slipped from the wrist pin without making it necessary to disconnect the tools from the temper screw.

Variations in the size of the parts of a rig depend on the amount and difficulty of the work to be performed. At Bradford, Pa., where few of the oil wells are more than 2,000 feet deep, the derricks are 72 feet in height; at Kittanning, where wells between 2,000 and 3,000 feet deep are common, the derricks are 82 feet high. An increase in the length and weight of the tools used is always accompanied by an increase in the size and strength of the derrick. The stems alone of the drills used at Kittanning are 39 to 42 feet long, and the sand buckets used with some outfits are 60 feet long. The walking beam used in this field is also larger than usual, being 24 feet long as compared with 16 feet at Bradford. At Kittanning the hemp drill rope is 2¼ inches in diameter; in the Bradford field it is 1¼ to 1½ inches. These figures show the structural changes that follow a change in the amount of work to be done.

For a 72-foot derrick about 13,000 board feet of lumber are required for the framework and wheels, and, if the derrick is closed in, about 3,000 feet of siding. In places where it is difficult to get skilled rig builders, as in the Philippines or in newly developed oil regions, bolted wood derricks are very serviceable. The timbers are all framed and distinctly marked, so that the derrick can be easily erected.

Steel derricks have not found much favor, though they are easily taken down, transported, and set up again, and offer slight resistance to the wind. The driller objects to them chiefly because of the delay and expense entailed by the necessity of sending to the supply house for repairs when a part becomes broken or twisted, whereas repairs on wooden derricks can be made quickly by unskilled labor and with cheap material. The loosening of bolts—a serious defect of the steel derrick—has been overcome, at the expense of considerable additional time in erection, by using a guard nut on each bolt.

A bolted wood or steel derrick may be set up in two or three days. Three or four skilled workmen can set up an ordinary nailed derrick in from three to five days, the time depending on the size of the rig and the quality and accessibility of the lumber; but after a nailed derrick has been used for two or three jobs it becomes too badly worn and racked to be set up again.

Where oil wells are drilled close together, or where, on account of trees or buildings, there is limited space for operation, a rig with a short walking beam is sometimes used. This rig occupies a plot about 20 by 50 feet in size, and is very compact and serviceable.

ENGINE AND BOILER.

Beyond the derrick and other parts of the rig is the engine, which furnishes power to the band wheel by a belt. Steam power is almost universally used and is supplied by a boiler placed a short distance from the engine. The throttle of the engine is controlled from the derrick by a double line of telegraph wire passing over small pulley wheels, and the reverse lever is operated by a rod that extends from the engine into the derrick.

A good engine and boiler are just as essential as a good drilling machine, and these parts of the outfit should be selected very carefully. The boiler used in connection with the standard rig ranges from 15 to 40 horsepower and the engine from 12 to 30 horsepower. Boilers are of two general types—horizontal and upright. The horizontal—called the oil-country boiler (see Pl. I, Q)—is in most general use. The upright boiler differs from the horizontal mainly in shape, but is smaller than the oil-country boiler, and is more easily moved and set up. It is used in some parts of the California fields, where it is closed in with natural adobe instead of brick. In many oil and gas fields either oil or gas may be obtained from other wells for fuel under the boiler.

Engines of various styles are used even in the same locality, but all are usually so fitted that they can be controlled from the derrick and are otherwise adapted to the particular needs of the work.

Water for the boiler and for use around the well may be obtained from a near-by water well or from a neighboring stream. If the source of supply is not too distant, a hose or pipe is led to the outfit and water is drawn by a steam pump, but if the distance is considerable the steam pump is put near the well or stream and water is forced up to a storage tank at the place where drilling is to be done. Steam may be supplied to the pump through insulated pipe led from the boiler, or a gasoline engine may be set up near the pump. Gasoline engines are used with many outfits in Indiana and Pennsylvania and are said to be more economical and to require less care than steam.

Where there is no near-by well or stream from which a water supply can be obtained, a water well is sunk by means of the outfit before work on the oil well can be begun. The water well is usually put down immediately beneath the walking beam, about 3 feet back from the point where the deep hole will be drilled, in order to lessen the labor of drilling it and of pumping the required water. Water for drilling this well and for the boiler is hauled from the nearest available source. After a water supply has been obtained, a pump is so installed that it can be connected with the walking beam, by which it is operated when water is needed.

In the vicinity of Bradford, Pa., water is obtained from wells about 60 feet deep in the valleys and 200 to 300 feet deep in the hills. The cost of sinking water wells adds considerably to the expense of putting down oil wells.

TOOLS.

The string of tools used in deep drilling consists of several parts, all of which have certain definite functions and are the outgrowth of years of experience. A full string (fig. 5, *A*) comprises rope socket, sinker bar, jars, auger stem, and bit. Whether or not the complete string is used depends on the conditions under which drilling is done.

The socket may be fastened to the drilling rope in several ways. It may have a tapered hole in which the rope is secured by knotting; the rope and socket may be riveted together, or the rope may be threaded back and forth through several holes in the socket and secured by wedging.

The sinker bar is a long, heavy bar, which is used to add weight and length and thus aids in keeping the hole straight. It was formerly thought to be an essential part of the string, but it is now seldom used unless a wet hole (one partly filled with water) is being drilled. It then assists in sinking the cable rapidly. If it is placed between the jars and the bit, it adds force to the blows of the latter.

The jars, as previously stated, consist of a pair of linked steel bars. When drilling in rocks in which the bit is apt to stick they are necessary to "jar" the drill loose. The drill responds to the powerful upward blow of the jars as they are jerked violently together by the stroke of the walking beam when it will not yield to the slow and relatively steady pull of the rope. In ordinary brittle rock the jars are now almost universally discarded, but they have a very important use in "fishing" for lost tools; those intended for this purpose are made longer than jars used in ordinary drilling.

The jars in no sense act as a maul to drive the drill into the rock, as many people suppose. In fact, a good driller so adjusts the cable that it is impossible for the upper jar to strike the lower one except when the cable is raised. The only weight which adds effectiveness to the blow of the drill is the weight of the lower jar, the auger stem, and the drill. The weight of these three parts, or of the two last-named parts, makes up three-fourths to seven-eighths of the total weight of the string of tools. This weight, falling through a distance of several feet, is all that the drill can bear. Some inexperienced drill men give the drill too much rope, so that the bottom of the upper jar strikes into the bottom of the slot of the lower jar at each downward stroke, and in a short time the links are seriously damaged. The stroke must be carefully adjusted to the play of the jars, taking into account the stretching of the rope.

The auger stem gives additional weight to the blows that are struck, and also, by increas-

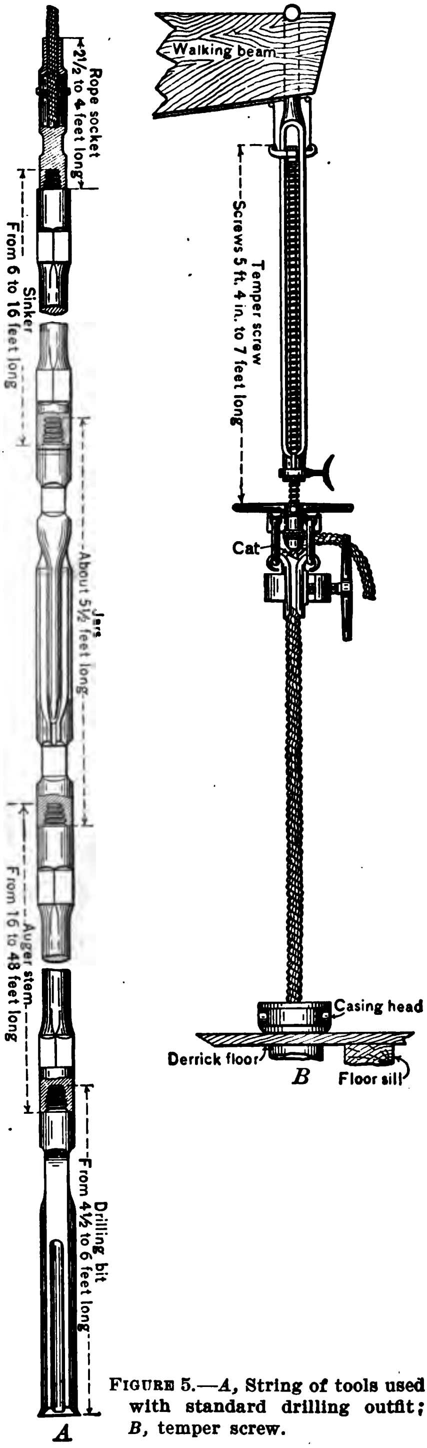


FIGURE 5.—*A*, String of tools used with standard drilling outfit; *B*, temper screw.

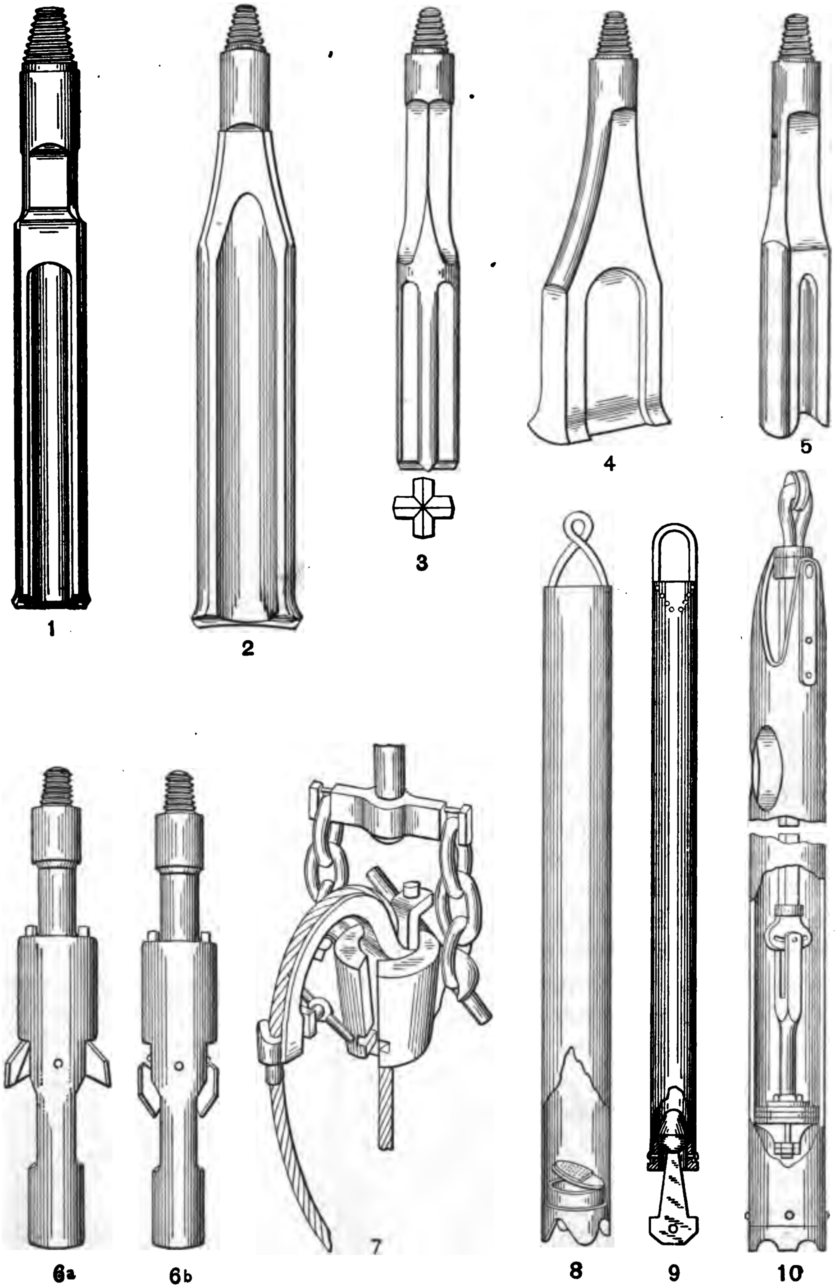


FIGURE 6.—Drilling tools used with standard drilling outfit. 1–5, Bits; 6ª, 6ᵇ, reamers; 7, rope clamp; 8, 9, sand bailers; 10, sand pump.

ing the length of the drill, helps to maintain a straight hole. It is of the same shape as the sinker bar, but is considerably shorter.

Various patterns of drilling bit are used, according to the character of the rock that is being penetrated. The shape illustrated at the bottom of the string of tools in figure 5, *A*, is used in moderately hard rock; the "Mother Hubbard" pattern (fig. 6^1) is a similar, but thicker, drill that is used in hard, fissured rock; the California pattern (fig. 6^2), which is concave on the bottom, is much used in the shales of the oil districts in that State. A shorter, lighter bit (fig. 6^3) is used in "spudding" at the beginning of drilling. Star bits (fig. 6^4) are sometimes used in creviced rock that dips steeply, and more complex shapes are used in reaming and in other special operations.

All joints of the string of tools have taper screws, so that only a few turns are required to fasten them together. They are screwed up tightly by heavy wrenches on which great leverage is exerted by means of a ratchet floor circle and jack (fig. 7, *A*), or by a simpler arrangement (fig. 7, *B*) in which the floor circle is an arc of band iron with holes punched in it every 2 or 3 inches. These holes give footing to a bar by which the upper wrench is forced around. The great stress that is thus brought on the screw joints binds the string of tools together. When first assembled and screwed together tightly each joint of the string may be marked by a cold chisel cut that extends across it, and each time a joint is put together care is taken to see that it is screwed up as far as or a little farther than it was before. If the two halves of the chisel mark fall short of coinciding, sand or mud in the threads may be the cause, and if this material is not removed and the joint screwed together tightly, the sand may work out, leave the joint loose, and cause loss of all tools below the joint.

TEMPER SCREW.

The cable supporting the string of tools is connected to the walking beam by a temper screw (fig. 5, *B*), which allows the drill to be fed downward as the drill hole is deepened. The temper screw consists of a frame or reins, at whose lower end is a split nut held together by a yoke clamp. Through this nut the main screw passes, and to its lower end is fastened a handle, by which it is turned. Below the handle is attached a ball-bearing swivel, from which depend the clamp links and rope clamps. The cable is gripped tightly between the rope clamps by a **C** clamp and is prevented from slipping by means of a "cat," made of strands of raveled rope or strips of coarse cloth, loosely plaited or twisted so as to form a cord about as thick as a man's finger in the middle, and tapering toward each end. The "cat" is wound about the cable at the point where the clamps are attached, and the set screw is then turned so as to bring the rope clamps firmly against it.

Slightly different forms of clamp (fig. 6^{7}) are sometimes used with wire rope.

When the screw has been run out its full length, and it is desired to bring it up again, the slack of the drilling rope is taken up on the bull-wheel shaft, the pitman of the walking beam is disconnected, and the C clamp is loosened. The yoke clamp is then loosened, the main screw is drawn up through the split nut, the yoke clamp is again tightened, and the temper screw clamped to the cable. Small ropes are fastened to the short crossbar, or elevator, at the upper end of the main screw, and by pulleys on the under side of the walking beam a counterweight is hung beside the samson post. This weight balances the temper screw and renders its raising easy.

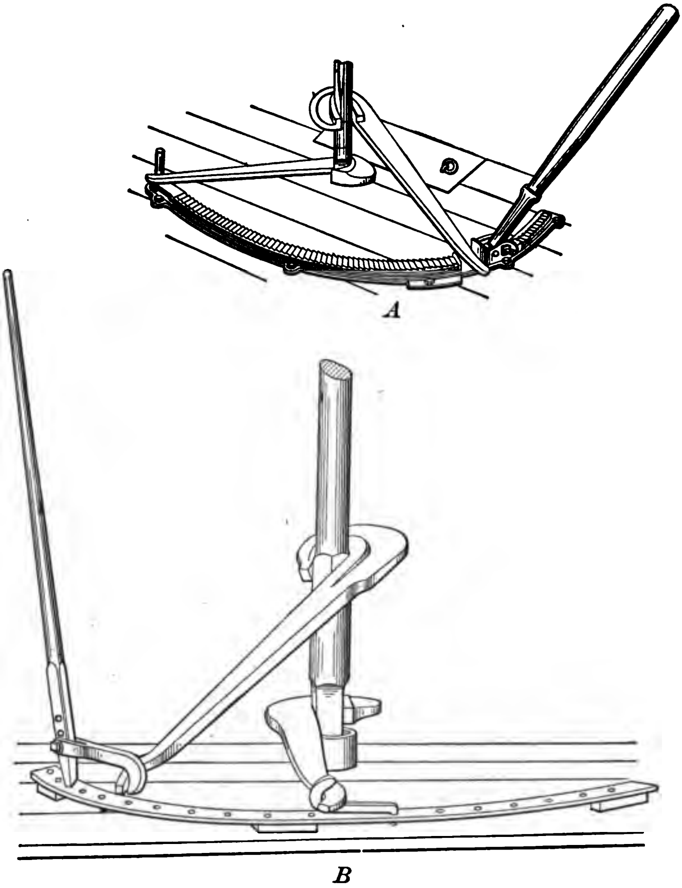


FIGURE 7.—Floor circles: *A*, Rachet and jack; *B*, bar and perforated arc.

A device employing hydraulic feed and intended to replace the temper screw has been patented within the last few years. It is attached to the walking beam in the same position as the temper screw.

It is simple in construction and operation, as it consists essentially of a cylinder containing a piston to which the cable is attached. Water may be admitted either above or below the piston, and by regulating its flow from the lower to the upper part of the cylinder the piston and tools are allowed to descend slowly as the hole is deepened. When the piston reaches the bottom of the cylinder the tools and piston rod are again elevated to the top, a process similar to that of raising the temper screw in that it involves a cessation of drilling. With both devices, however, the adjustment is usually made only when the tools are withdrawn for sand bucketing the well.

The device has been patented too recently and used too little to enable one to judge of its merits. As it has a larger number of small and special parts than the temper screw, its use will not be approved by many drillers, for it may cause expensive delays when parts are broken. Accidents to the temper screw may usually be remedied by a local blacksmith. The new device is more easily manipulated than the temper screw, however, and this advantage may lead to its adoption.

CABLE.

Both hemp and steel-wire ropes are now used for drilling cables, the steel wire having come into more general use during the last ten or fifteen years.

The best quality of hemp rope is that made of manila hemp (not common hemp nor sisal) and is hawser laid, that is, it consists of three ropes of three strands each, twisted together into a single rope. In its manufacture a " nap " is formed, of the ends of hemp fibers, nearly all of which point toward one end of the rope. The rope socket should be fastened to the end toward which the fibers point, for although when the tools are attached to this end the fibers spread out and retard the downward stroke in a hole that is partly filled with water, they protect the rope better from being frayed by rubbing against the casing on the upstroke.

Steel-wire drilling cable is composed of several strands wound about a hemp center, each strand being formed of several wires. Rope consisting of six strands of seven wires each is a style commonly used.

The advisability of substituting steel-wire cable for hemp cable in drilling deep wells has been much discussed, some maintaining that hemp can never be replaced by steel, and others that steel will shortly be used altogether. The importance of the substitution of steel for hemp is better appreciated when it is known that a hemp cable ordinarily can not be used to drill more than one or two wells, but the hemp cable possesses certain important qualities which are not found in the steel cables and which must be considered in dealing with the problem. The careful driller never allows his tools to fall as a dead weight on the rock which he is drilling, but so adjusts the rope that the tools will stretch it in reaching the bottom of the hole. The nature of this action may be illustrated by suspending a weight by a piece of rubber elastic a little above a table or other surface. It will be found that by giving a slight reciprocal motion to the rubber the weight may be made to strike the surface with considerable force. Manifestly, the force of the blow is diminished by this arrangement, but in drilling this loss of force is more than compensated by the springing blow that is struck; and if the rock is easily cut by the drill this rebound is essential, as otherwise the drill will be imbedded so firmly as to make it difficult to remove except by jarring.

In drilling a deep well the stretch of the rope is often underestimated, and it may happen that the tools are falling when the walking beam is rising, thus bringing a great strain on the cable and making the blows of the drill very ineffective. The operation of the tools is rendered still more difficult when the hole contains several hundred feet of water, which interferes with the free upward and downward motion of the cable.

Steel cable, with its smaller diameter and greater weight, has the advantage of passing comparatively freely through water which may stand in the drill hole, the water friction being much less than on a hemp cable, and the water also reduces the shock of the steel cable by acting as a deterrent to the rapid drop of the tools. On the other hand, steel cable has very little elasticity, and drilling by the stretch of the rope is hardly possible. Every blow that is struck by the drill is a dead blow, as there is no compensating rebound and the upward stroke causes severe strain, both on the derrick and on the cable itself where it is attached to the tools at its lower end and to the temper screw at its upper end. The difference in stretch of the two kinds of cable is shown by the fact that with a 5-foot temper screw 7 or 8 feet may be drilled with hemp cable, while at best a distance of only 5½ feet is possible with steel cable. Some drillers use 150 or 200 feet of hemp rope between the tools and the steel rope, and this gives some elasticity to the cable and rebound to the tools.

The use of the steel cable was considerably increased during the Spanish-American war by the fact that the price of hemp cable became so high that its use seriously increased the cost of a well.

In the last few years at least half of the oil wells put down in the California fields, where the wells are usually drilled "wet," have been drilled with steel cables. In other oil fields a very small proportion of the drilling is done with steel cables. For cleaning wells, however, it has largely supplanted hemp cable throughout the East, as in this work it is not necessary to use such a rapid stroke, and hence steel cable may be advantageously employed.

Experiments have been made by several supply companies looking toward the construction of some device that will give elasticity to a steel cable, but the thousands of dollars thus spent have had little practical result. Several experimenters, however, are continuing this investigation, working along the line of a spring fastened to the walking beam, the whole being adjusted in such a way that the spring, when given the proper tension, will take up the slack of the cable on the upward stroke and give it out again under the weight of the tools on the downward stroke. Experiments are also being made with a cushioned walking beam, looking toward the same result; and it is possible that a sufficient degree of efficiency may be reached in the construction of this device to permit the wider substitution of steel for hemp in future drilling operations.

The standard well-drilling outfit with steel-wire drilling cable has been used to some extent in the Baku oil region of Russia, where it was found that only a very limited amount of rotation could be imparted to a wire rope without damaging it, because of the untwisting and kinking of the strands. To overcome this disadvantage a special kind of wire rope was employed, consisting of left-hand and right-hand strands plaited together. It is said that this rope worked satisfactorily in the hands of a skillful attendant, but it had to be disconnected from the main drum at each change of operations.

DRILLING OPERATIONS.

SPUDDING.

The term "spudding" is often misunderstood. By some people it has been thought to mean the preliminary part of drilling, without reference to the way in which the drilling is conducted; by others it has been interpreted to mean drilling in rock of unusual hardness. Properly, however, the term is applied to drilling without the aid of the walking beam—the method nearly always used in sinking the first 75 or 100 feet of a well, as the string of tools is too long to be operated from the walking beam in beginning work. It is possible to attach the tools to the drilling cable before the hole has been drilled to this depth, but owing to the short length of cable between the tools and the walking beam there is very little "spring" in the rope, and the hole must be spudded to a sufficient depth to allow a considerable length of cable to come between; otherwise the blow of the drill will be "dead" and the rope will be likely to break.

For spudding a short cable is run through the crown pulley at the top of the derrick, one end being attached to the bull-wheel shaft and the other to the rope socket, to which are usually screwed only the auger stem and spudding drill. The drill may be given an up-and-down motion in two ways: In the first method the rope is carried around the bull-wheel shaft in two or three turns, its end being left free. A man standing in front of the bull wheels grasps this free end of the rope and gives a slight pull, causing the coils to tighten and grip the revolving shaft, and by this means raising the tools; when the rope is slackened the tools fall. By alternately tightening and slacking the rope the operator may raise and drop the drill. The second method has come into use comparatively recently and is much more effective than the other. In this method, which is self-adjusting, the drill rope is wound firmly about the bull-wheel shaft and passed through the crown pulley, and from its end the tools are suspended in the drill hole. A rope called the jerk line is attached to the wrist pin of the band-wheel crank, brought inside the derrick, and attached to the part of the drilling cable which extends from the crown pulley to the bull-wheel shaft by a curved metal slide called a spudding shoe. (See fig. 8.) By carefully adjusting the length of this rope each revolution of the band wheel results in a pull on the line and its subsequent release, and a corresponding rise and fall of the tools. As the hole is deepened the cable is let out by giving the bull-wheel shaft a partial revolution, and the spudding shoe is slipped farther and farther down, for this downward sliding of the spudding shoe increases the length of the pull on the drilling cable and hence the distance through which the drill drops. The sliding motion is imparted by the driller's assistant, between the jerks of the line, by means of a crooked stick long enough to reach the spudding shoe from the floor of the derrick.

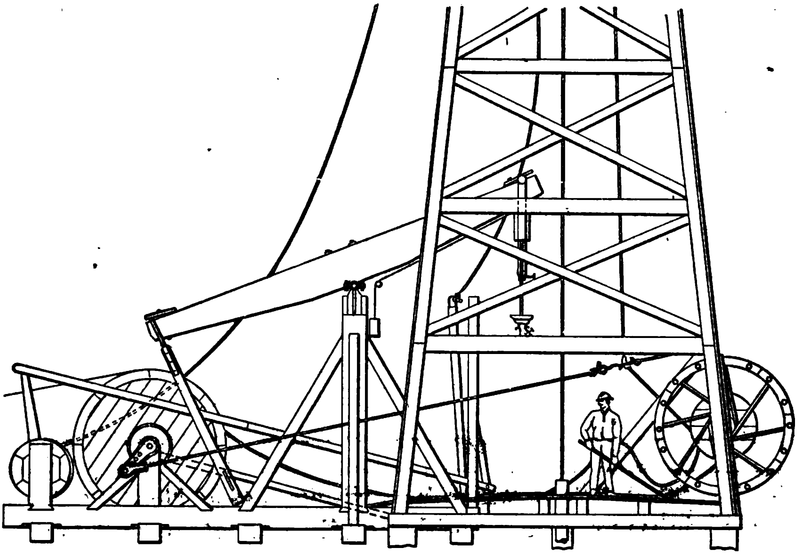


FIGURE 8.—Standard rig arranged for spudding.

Spudding is much harder on the derrick than is ordinary drilling, as the strain is brought on the top of the derrick where there is the greatest leverage. In drilling with the walking beam the weight comes on the samson post, which is not directly connected with the derrick, and the strain comes on the derrick only when raising or lowering tools or casing and when using the sand bucket or the bailer.

DRILLING WITH THE WALKING BEAM.

After the hole has been sunk to the depth required for the string of tools a heavier drilling bit is attached, the drill rope is suspended from the walking beam by the temper screw, and regular drilling by means of the walking beam is begun. To allow freedom of motion to the walking beam, 20 or 30 feet of the drill rope are unwound from the bull-wheel shaft and loosely coiled on the floor. The pitman of the walking beam is then fastened to the wrist of the band-wheel crank. The crank is provided with a number of holes, so that the length of stroke can be adjusted to the depth of the well, a short stroke being used near the surface, as the strain would otherwise be too great for the rope to bear. The engine is then started and the walking beam begins rocking up and down, raising and dropping the tools at the rate of about 25 strokes a minute.

Until within the last few years it was the custom to revolve the drill by inserting a stick in the rings below the temper screw and slowly turning the rope first in one direction and then in the other. This was thought to insure a round hole by causing the drill to strike each time in a different place. One day a tired workman, who wondered if this operation was necessary, neglected this precaution and found that the drill still made a round hole, a fact that had often been inferred by drillers who had seen the tools revolve and bring the drill in a new position for each stroke. The drill is jerked free from the rock unevenly, and the torsion of the drilling cable under the lifting strain has the effect of rotating the tools in one direction on the upstroke and in the other on the downstroke. This action, however, takes place to a notable degree only when there is a sufficient length of rope between the tools and the walking beam; until a considerable depth is reached it is often necessary to turn the cable by hand, otherwise the drill may strike successive blows in the same place, but it is now rightly considered that after the hole is 200 or 300 feet deep it is needless to turn the rope while drilling.

The skilled workman takes hold of the rope or swivel often, for by the feel of the rope he ascertains whether the string of tools is intact and the drill is cutting the rock. When the drilling bit strikes the bottom of the well, the cable is drawn taut and conveys the vibration to the driller's hand; by this means he soon learns when to adjust the temper screw. In the same way the operator learns whether or not the jars open and shut at each blow of the drill.

The proper tension of the cable can be determined only by practice. An old cable has more spring to it than a new one; and the weight of the drilling tools, the depth of the hole, and the speed at which the machine is running must also be taken into consideration. Ordinarily the engine should be speeded up until the cable tightens slightly in advance of the stroke of the drill, not so as to retard its fall, but so that when the drill touches bottom it will be instantly lifted, with no time either to settle or stick. This careful adjustment of the stroke is absolutely necessary for rapid and skillful work. If the drill touches bottom when at rest, there is too much rope out and it should be taken up with the temper screw, for the downward stroke of the drill will stretch the rope sufficiently to let the bit strike the bottom of the hole.

The motion of the drill will be greater than that described by the walking beam, unless too much cable is let out, in which event the stroke of the drill will be less than the stroke of the walking beam, the strain on the cable will be greatly increased, and little or no progress can be made. One of the hardest things for a beginner to learn is that he can not make the drill cut faster by letting out more cable. With a hemp cable, at a depth of about 50 feet, when the drilling tools are at the lowest point in the stroke, the point of the bit should hang 2 or 3 inches above the bottom of the hole. At 100 feet it should be 4 or 5 inches; at 200 feet it should be 6 to 12 inches; and at greater distances with greater depths. An unskilled driller will sometimes allow the full weight of the tools to fall on the drill rope, the drill actually being stopped in its descent a short distance above the rock in which it is supposed to be cutting. The likelihood of such an occurrence increases with the depth of the hole, for the increasing weight of the drill rope added to the weight of tools, often several tons in all, makes it difficult to detect by the "feel of the rope" whether or not the total weight is decreased at the end of the stroke by the weight of the tools below the jars.

As the drill cuts deeper it is necessary to let out the drill rope gradually, so that the drill will strike bottom at each stroke. This is done by loosening the yoke clamp a little, and running out the temper screw a turn or two. At the end of from half an hour to several hours the temper screw has been run out its length of several feet and the drill has advanced an equal or greater distance. The tools are then withdrawn, the waste that has accumulated since the last bailing is removed with the sand bucket, and if necessary a sharpened bit is substituted.

The withdrawal of the tools is accomplished by first taking up the slack cable on the bull-wheel shaft, thus transferring the weight of the tools to it through the crown pulley. The rope clamp is then loosened, the temper screw is disconnected, and the pitman is thrown off from the band-wheel crank pin, as in figure 8. By rotating the bull-wheel shaft with the engine connection, the tools may then be raised or lowered at will. This part of the work demands skill, for if the bull-wheel brake should not be applied as the tools reach the surface, the crown block and pulley would be torn loose and the tools would fall on the workmen beneath. After the tools are clear of the hole, they are swung to one side and caught in the loop of a quarter-inch rope fastened to a leg of the derrick.

The operator is now ready to bucket the drillings from the well. The sand bucket, or bailer, consists of a section of tubing 15 to 60 feet long and somewhat smaller than the well. It has an iron valve at the bottom, either of the flat pattern, or the ball and tongue pattern. (See fig. 6 $^{8-9}$.) In some materials in which the drillings are thick and heavy and do not readily enter the bailer, a sand pump (fig. 6^{10}) is used. In addition to the bottom valve this has a plunger which is worked like that of a water pump, and thus sucks the drillings into the tubing. The bucket or pump is suspended from a wire cable that is wound on the sand-line reel and carried through the sand-line pulley. The reel is operated from the derrick by a lever, which brings its friction pulley into contact with the band wheel. The sand-bucket line is thus wound up and the sand bucket is swung over the hole. The friction bearing on the band wheel is then released and the bucket is lowered into the well at any desired speed. As the drillings form a thin mud, owing to the addition of water from time to time by the driller, they rise into the sand bucket, are retained by the valve in its bottom, and are then removed. The bucket is emptied by lowering it upon an upright stake or pin beside the well, thus opening the valve.

The liquid condition of the drillings often makes it possible to drill 5 or 6 feet without bucketing; otherwise the drill would become ineffective at the end of a very short time, by striking into its own cuttings, and the necessity for frequent bailings would greatly increase the work and cost of drilling. Water is usually added to the drillings by the bucketful at the well head. Sometimes it comes into the well from water-bearing strata that have been penetrated by the drill in a quantity sufficient to soften up the drillings, and yet not great enough to interfere with the work. It is then unnecessary to pour in water from the surface.

In many localities water is added to the drillings by means of a barrel set at one side of the derrick, from the lower end of which a pipe extends within 2 or 3 feet of the drill hole; to this pipe is fastened, by a loose joint, another piece of pipe as long, at least, as the height of the barrel and long enough also to reach from the end of the horizontal pipe to the mouth of the drill hole. When the short length is dropped to a horizontal position water flows from the barrel down into the hole; by raising the short pipe to a vertical position the flow is shut off.

DRESSING THE BIT.

As the bit gradually becomes worn on the edges, its diameter is constantly reduced—that is, it loses its gauge. When the tools are withdrawn, if the bit has become noticeably worn, the screw joint connecting the bit and auger stem is "broken" by means of the wrenches and floor circle, the bit is unscrewed and removed by hand, and a freshly dressed bit is then substituted. During the first part of this operation the tools are steadied by keeping them partly in the drill hole. At this time the whole string of tools is usually examined, and each joint is "set up" in turn, as the constant and tremendous jarring to which the tools are subjected tends to loosen the different parts. Before drilling is resumed the temper screw is also screwed up or "elevated" so that it can be fed down as the drill hole deepens. The tools are then let down again and drilling is resumed.

The worn bit is heated in the forge, the circular tool gauge is slipped over while it is hot, and the edges of the drill are hammered out to fit the gauge, which has a diameter one-eighth inch greater than the required diameter of the bit to allow for contraction due to cooling. In heating the bit it should be turned occasionally to get an even heat, and brought to a cherry red for a distance 3 or 4 inches back from the end, so that in hammering it the outer part will not tend to spall off. It is usually spread with a sledge, working from the center to the edges, to a diameter a little larger than the gauge, and then hammered down to proper size. The edge should not be made very sharp or it will tend to drill a three-cornered hole. In tempering the end is heated until it shows bright cherry red in the shade, then placed upright in 1½ or 2 inches of water so as to cool only the part to be tempered. After a minute or two, when the edge is cool, the bit is removed until the heat flows back into the end and causes it to pass through straw, orange, and purple to a blue color. It is then re-immersed and allowed to cool. The treatment gives the proper temper for drilling moderately hard rock. If the bit is cooled at one of the colors that appear earlier, it will be too hard and brittle to work well, and if allowed to wait longer before tempering it will be too soft. The upper (threaded) end of the drill should be thoroughly cooled before it is screwed to the stem, otherwise subsequent shrinkage may cause the joint to loosen.

As the bit becomes worn by continued drilling, the size of the hole is correspondingly decreased. In hard sandstone one-quarter to three-eighths of an inch may be worn from the width of the bit in drilling 3 or 4 feet, so that when a newly dressed bit is introduced it may find the last few feet too small, and may work hard or even stick for the first few strokes. A well-worn bit will cut a hole no larger than its shank, but a newly dressed bit provides clearance, like the teeth of a newly set saw. To prevent sticking the bit is run up and down a few times and turned constantly. It is thus prevented from forming a groove which it would tend to follow so as to direct the repeated strokes of the drill in the same place. When the rock is very hard and the bit is more rapidly worn jars are necessary to prevent accident to the drill rope by the sticking of the drill.

WET AND DRY DRILLING.

A "wet" hole is one in which water in excess of that required for the operations is present while drilling; a "dry" hole is one in which excess water is cased off during the sinking of the well. In oil fields these terms are applied in a different sense, a wet hole being a well which yields oil and a dry hole one which does not.

In a dry hole the drilling can be done faster, as the tools are not buoyed up by water; the rope lasts longer because it is not always saturated; small showings of gas and oil are more readily detected and their depths are more accurately determined; and if the tools are lost in the hole, they can be more easily recovered, as fishing tools are used to better advantage in a dry than in a wet hole. At Bartlesville, Okla., three water-bearing sands are encountered in drilling for oil. Dry drilling in that field is regarded as so much more satisfactory than wet drilling that three strings of casing are inserted to keep the water out. Two of these are withdrawn when the well is completed, the last one that is inserted being kept in service to retain the oil and prevent the well from caving.

Wet drilling is usually cheaper (there being no outlay for additional casing), no time is lost in putting in casing and replacing the tools by a smaller set; and when the well is down, the charge of nitroglycerine used in shooting the well has much greater effect, as it is tamped by the heavy column of water. The greatest disadvantage of wet drilling is that the sides of the hole are kept so wet that some of the shales are reduced to a semifluid mud, which frequently caves. Another disadvantage is that when tools are lost there is danger of sand and mud settling around them, even if the sides of the well do not cave.

CASING THE WELL.

CONDUCTOR BOX.

In many places the surface material consists of loose sandy clay, sand, and gravel, varying in thickness (in the Pennsylvania oil regions) from a few feet on the hills to several hundred feet in the valleys. To restrain this material, which would otherwise impede the work of drilling, a conductor box, made of plank, circular, square, or octagonal in shape, and 8 inches to 20 inches across, is sunk to the bed rock. If the rock lies only a few feet below the surface the necessary excavating is done by hand; if the soil is deep, a large drilling bit is used to spud down a hole, into which the conductor box or a section of large iron pipe may be sunk as fast as drilling proceeds.

CASING AND DRIVE PIPE.

After passing through the surface material the drill enters the "live" rock. As a rule this rock is made up of alternating layers of hard and soft, of very porous and slightly porous, of water-bearing and nonwater-bearing rock. Unless the water in the rock is under notable head and is considerable in amount, it is welcomed by the driller, as it saves the trouble and expense of pouring into the hole sufficient water to keep the drillings liquid. If, however, the water coming into the hole is too great for rapid drilling, it is necessary for the driller to insert a string of casing extending from the surface into the first hard, nonwater-bearing rock that is encountered after passing through the water-bearing layer. This casing is set very firmly into the hard layer and shuts out the water. In order to continue drilling, it is necessary to use a smaller bit which will pass, with clearance, inside the casing. If other heavy flows of water are encountered at greater depths, each flow must be cased off by a string of casing extending from the surface to the bottom of the water-bearing layer. As each string must slip inside the preceding one, a smaller drill must consequently be used after each casing operation.

The first well lining used in this country was in the celebrated well drilled by Colonel Drake on Oil Creek, Pennsylvania. Some of the early drilled wells of small diameter were lined with pipe made of riveted or soldered sheets of copper. Before long this was superseded by drive pipe with soldered brass screw joints, such as is still used in the salt wells of Tarentum, Pa.

Several varieties of casing are now used. Sheet-iron riveted pipe is extensively employed in the Russian oil fields, but it is little used in oil wells in the United States. It is rather short lived, and the corners of the bit are apt to catch on it in drilling and cause breaks. Another kind of pipe used, known as oil-well casing, ranges in usual sizes from 4 to 12 inches, inside diameter, and is made in several weights. A third kind, called steam pipe, is also made in sizes up to 12 inches and in three grades—standard, extra strong, and double extra strong. Still another kind of lining is the regular drive pipe, which is made very heavy in order that it may be driven to great depths. The ends of the pipe are cut off smoothly and meet squarely in the middle of the sleeve coupling (fig. 9[1]). In this way the

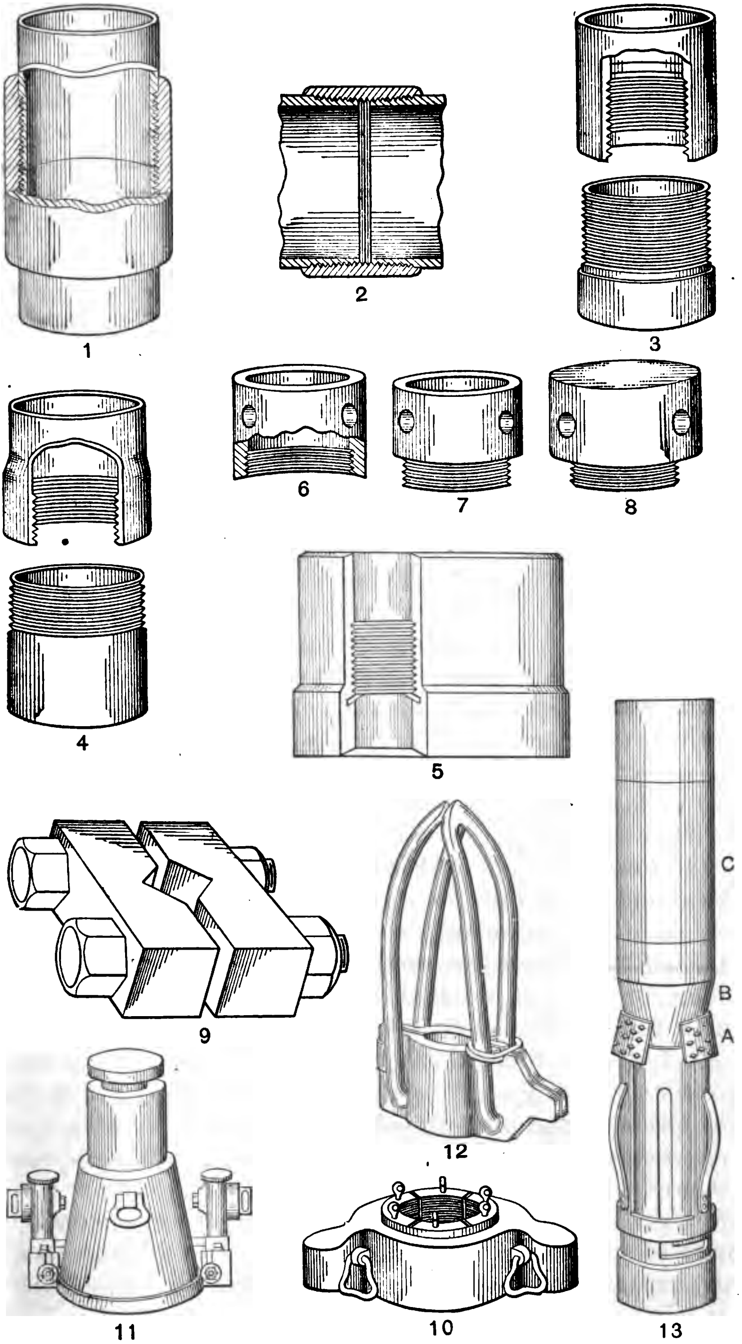


Figure 9.—Couplings and casing attachments. 1, Sleeve coupling; 2, tapered sleeve coupling; 3, 4, sleeve and inserted joint couplings; 5, shoe; 6, 7, 8, drive heads; 9, drive clamps; 10, pipe ring; 11, hydraulic jack; 12, elevator; 13, gas packer.

whole strain in driving comes not on the threads, but on the pipe; otherwise the joints would be disabled before reaching any considerable depth.

If a cheap well is desired, heavy wrought-iron pipe is driven to rock, and the well is finished by drilling to the required depth. A casing made of sheet iron, one-sixteenth inch thick and one-half inch smaller than the drilled hole, is then used. If it is necessary to shut off sand the bottom of this pipe may be flanged outward a little. After the sheet-iron pipe has been placed in the well the heavy pipe may be pulled out and used again. If the depth to rock is not more than 50 or 75 feet and the material is all clay or earth which will not cave, the heavy pipe may not be used at all, the sheet-iron pipe serving in its stead, though its use in this way is attended by considerable risk.

Casing is usually a lighter and cheaper pipe than drive pipe, as it has little outside pressure to withstand. A tapered sleeve coupling (fig. 9^2) is often used with it. In this form of coupling the last thread in the tube is the weakest and most likely to break in case of accident, and the pipe is easier removed than if the whole thread remained in the tube. Flush joint and inserted joint couplings (fig. 9^{3-4}) are also used with casing that requires little driving. After a few wells have been sunk in a district the approximate amount of casing that will be required for a well can usually be estimated, since the depth to troublesome water-bearing formations is then roughly known.

In gas wells, where dryness is essential, all the strings of casing are usually left in the well to prevent water near the surface from sinking to the lower end of the last casing, where it would be under great head and might force its way through a weak spot at the point of juncture of the casing with the rock. As a cubic foot of water weighs about 62½ pounds, the pressure, in pounds per square inch, of the column of water in the drill hole is equal to the height of the column in feet, multiplied by 0.434. Therefore at the bottom of a well 1,500 feet deep water that enters and fills it up to the 500-foot level exerts a pressure of 434 pounds per square inch. This is the crushing stress on the pipe provided there is no internal column of liquid to counterbalance the external column, as, of course, there is not in a producing gas well.

In deep drilling, where caving material may be encountered, it is customary to sink casing, or drive pipe, as fast as drilling proceeds. For this purpose pipe heavier than the usual casing is employed, and stronger joints are made generally by heavy sleeve couplings (fig. 9^1). On the bottom of the lower joint there is screwed or shrunk a shoe of tempered steel (fig. 9^5), which will stand heavy driving without injury, and which gives clearance for the pipe and couplings.

The ordinary pipe would be greatly damaged in driving long distances if it were not protected by this shoe. To prevent the top of the pipe from being battered, a drive head (fig. 9^{6-7}) is screwed or placed on it. In some places the material is so loose that the tubing will follow the drill for some distance without requiring to be driven; but when driving becomes necessary drive clamps (fig. 9^{9}) are bolted to the pin square of the upper end of the auger stem. The machinery is then coupled as for spudding, and 50 or 60 blows a minute are delivered by this driving clamp to the drive cap on the top of the pipe. The pipe may also be driven by a heavy wooden maul attached to the drill rope. In this case a solid drive head (fig. 9^{8}) is used, and proper direction and effectiveness are insured to the blows by means of temporary guides set within the derrick.

Sometimes in drilling through a compact formation, such as clay, the pipe becomes lodged, owing to the projection of the couplings. When this happens a cap is screwed to the drive pipe, and water is forced down it so as to come up outside of the pipe and loosen the material about the coupling.

When the pipe has been driven as far as practicable drilling is resumed. The driller endeavors to keep the hole sunk a few feet ahead of the casing, for in this way the casing is let down straight, whereas if the pipe is driven ahead of the drill, it may be deflected from its course by changes in the hardness of the material or by encountering a bowlder or a layer of coarse gravel.

This method, however, can only be used where the material will stand up for some distance without the support of the pipe. Quicksand will flow around the bit and even rise in the pipe, and in this material the pipe must be driven down to the bottom of the hole and kept ahead of the drill. If the bed of quicksand is not thick, the difficulty of drilling through it will be slight, but where beds 50 or 60 feet in thickness are encountered, some of the greatest difficulties known to well engineers have to be met and overcome.

When long and difficult strings of casing or drive pipe are to be withdrawn or "pulled" from a well, as on completing or abandoning it, a pipe ring (fig. 9^{10}) is placed over the upper end of the pipe; this ring grips the casing firmly by means of its corrugated iron wedges and is then subjected to upward pressure by specially designed hydraulic lifting jacks. (Fig. 9^{11}.) When short or easily pulled lengths are to be removed, wrought-iron elevators (fig. 9^{12}) are clamped to the upper end of the last length of pipe, are caught by a hook suspended from the derrick, and are tugged upward by means of pulley sheaves.

Several machines for pulling casing are on the market. For pulling casing from abandoned wells they have the great advantage of portability, and they are cheaper and more efficient than a derrick erected over the well.

PORTABLE DRILLING RIG.

VARIATIONS IN CONSTRUCTION.

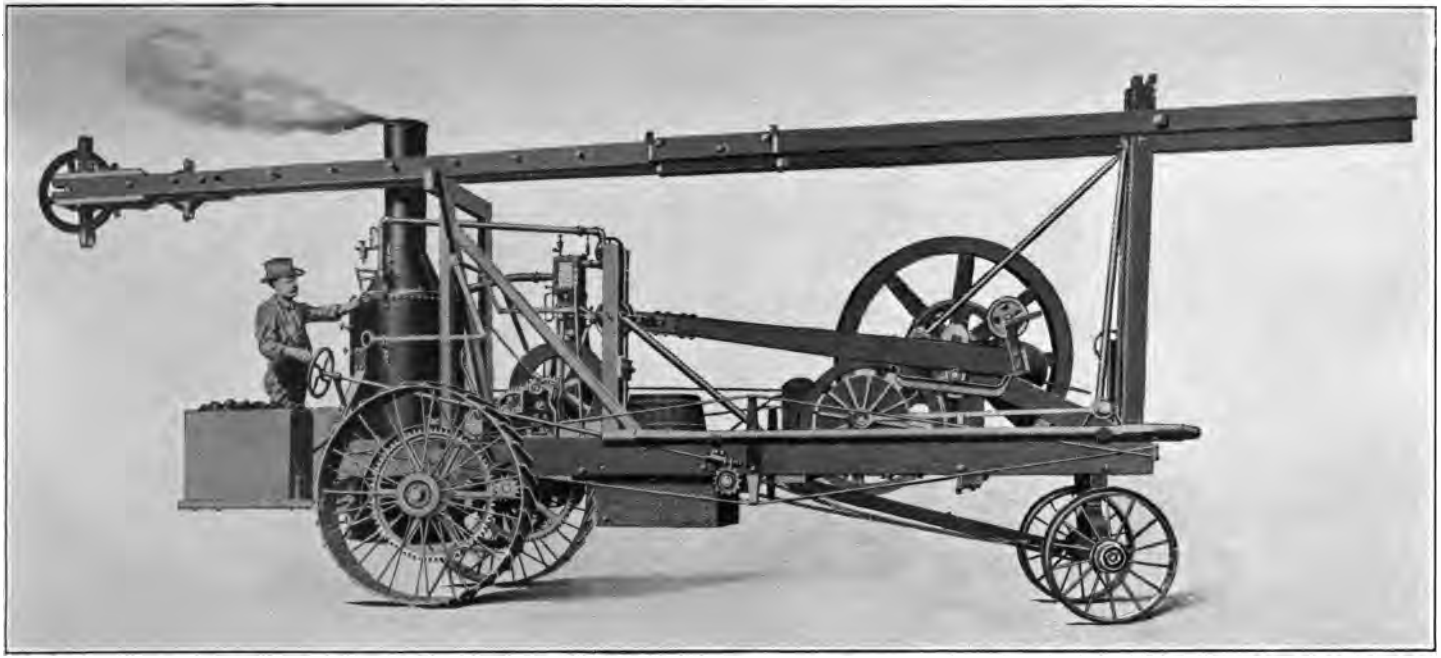
Several modified forms of the standard outfit, called portable rigs, are made. These rigs are built in compact form, on heavy frames, and are usually mounted on wheels. Horses are commonly employed in moving these rigs, but in favorable localities a traction engine supplies power for the machine when in operation and hauls it when it is to be moved. A steam or gasoline engine is used, and the engine may or may not be mounted on the frame with the other machinery.

In mode of operation and in the kind of tools used these portable rigs are like the standard outfit, but most of them are lighter and they can not be used to drill to as great depths. Certain parts of the machinery, such as the hoisting gear and sand reel, are usually placed within the frame, and are operated through either cog or friction-power transmission.

The difficulty of weight in transportation is one which the manufacturers have been working for a long time to overcome. Every part of such rigs has been carefully tested and the experience of operators taken into account, so that machines made at the present time represent the maximum strength with the minimum amount of material, and any decrease in the weight of any part would mean a decrease in effectiveness and durability. The total weight of a portable rig is usually about 15,000 pounds, though lighter outfits may weigh only 5,000 pounds, and some of the heavier ones weigh 20,000 pounds or more.

In most portable machines support for the hoisting sheave is provided, not by a derrick, but by a mast, which is erected over the front of the rig, and brings the sheave over the spot where the well is to be drilled. In hauling the machine from place to place the mast is tilted back over the machinery, as shown in Plate II.

To make the portable rigs more compact the walking beam is made 2 to 6 feet shorter than the walking beam of the ordinary standard rig. The shortened stroke which results becomes a disadvantage only when the hole reaches considerable depth. In the first few hundred feet the stretch of the rope is so slight that the short walking beam is nearly as efficient as is the usual walking beam of the standard rig; at greater depths the total stretch of the rope is so increased that unless the stroke of the walking beam is correspondingly lengthened the machine will drill on the tools; that is, when the walking beam is coming up the tools will be going down. If the walking beam is properly adjusted, however, drilling may be conducted to a depth of 1,000 or 1,500 feet. Beyond 1,500 feet the stroke of most portable machines becomes so short as to make them less efficient than the standard outfit.



PORTABLE DRILLING MACHINE, USING STEAM-POWER TRACTION.

Showing derrick folded, spudding bar, etc.

A technical description of the details of each of the many styles of portable well-drilling machines can not be given in this report, and it would be obviously improper here to designate by name those supposed to be the best or those having manifest disadvantages. Each rig includes some device which makes it in certain respects superior to others, but no portable well-drilling machine is perfect. Unfortunately the invention of a new device usually results in building a new machine, and the embodiment of all good devices in one nearly perfect machine is impossible on account of patents.

The leading portable drilling machines are so fully described in the manufacturers' catalogues that a driller can readily note the important points and advantages of each style. Some rigs have special devices for rapid spudding, as spudding is in many wells carried to a depth of 100 feet, or even more, and forms so large a part of the sinking of wells less than 1,000 feet deep. One way of obtaining a spudding motion is shown in figure 8. Some rigs have devices to shorten the time for changing from drilling to bailing, such as variations in the form of the pitman, so that it need not be disconnected from the crank pin in changing from one operation to the other. Others have special devices for deep drilling. Several portable rigs are adapted to using self-cleaning or hollow-rod tools, and one or two are fitted to operate hydraulic rotary and core-drilling tools.

ADVANTAGES AND DISADVANTAGES.

Most portable rigs are not intended for deep, heavy work and do not come into competition with the standard outfit, though of late years heavy, semiportable rigs with a capacity of 2,000 feet or more have been built for oil drilling. Both portable rigs and the lighter styles of the standard outfit are used in drilling wells between 500 and 1,500 feet in depth.

Portable rigs are often used in cleaning out oil wells, which are also cleaned by erecting derricks over them and stringing the tools as in beginning a well; but as the work involved in cleaning is not very great a lighter and cheaper outfit than the standard can be used to advantage.

Portable rigs are also used in prospecting for gold in Siberia, Australia, Argentina, and South Africa, and in drilling blast holes for large excavations such as the Panama Canal.

The chief advantage of a portable rig is that it can be easily and cheaply moved after the well is completed, whereas a standard outfit must be torn down and rebuilt for use in a new location.

In some localities, as in southern Illinois, where the country is flat and the difficulties of transportation during the rainy season are great on account of muddy roads, drillers with standard outfits are usually able to tear down and rebuild the derrick in a shorter time than would be required to haul a portable rig to a new location and set it up. Drillers near Casey, Ill., claim that they can set up a standard outfit twice and drill two wells with it in the same time that one well can be drilled with a portable rig. The standard derrick used near Casey is 60 feet high and is built of light timber in skeleton form, except in stormy weather. This outfit will drill a hole 500 feet deep in about five days; a portable rig would consume ten to fifteen days.

When made in this light form the standard rig is taken down in sections, each of which is placed on a pair of trucks and hauled from place to place more easily than a portable rig, which must be moved as a whole.

Once in position the standard rig is preferable to the portable on account of its greater rigidity, the larger space it affords for handling tools, oiling bearings, and repairing broken parts, and the better protection it gives during stormy weather. The compactness of some portable rigs makes it difficult to oil or adjust the machinery while in operation without danger, or at least without great discomfort, to the workmen. The extra work of lifting large wrenches and drill bits to the drilling platform when adjustments are necessary is also very considerable. Breakdowns with a portable rig are annoying and expensive, as the driller must often send to the factory for the broken part; whereas most breaks in a standard outfit can be repaired by a local blacksmith or carpenter, or by the workmen themselves.

With portable rigs the bits are dressed in the open, and there is no shelter for men or tools from sun or rain. Shelter can of course be provided for both rigs, but more easily for the standard, since the derrick posts form a frame that needs only to be boarded in. Owners of portable rigs expect workmen to do without a shelter, but the shed is a usual part of the standard outfit. If a shelter always had to be built for a portable rig the extra labor required would leave little advantage in favor of this machine. The flywheel and gearing, however, are often protected in rainy weather by a lean-to.

Much of the difficulty that has attended the use of portable machines may be attributed to the fact that the men engaged to operate them have been accustomed to standard outfits and are prejudiced in their favor. Drillers have been severely criticised by manufacturers and well owners because of this prejudice, asserting that every improvement devised was condemned by the drillers because it was novel and at first somewhat difficult to manipulate. In a measure this is true, but it should be remembered that these men are trained in the oil fields of Pennsylvania, Ohio, Indiana, and West Virginia, where the standard outfit is largely or exclusively used, and, having slight knowledge of mechanics aside from that gained in actually operating standard outfits, they look with disfavor on portable rigs.

A man who begins his drilling experience with a portable rig is always enthusiastic over the machine and its possibilities. This is especially true of drillers of water wells ranging in depth from 400 to 500 feet.

That portable rigs are adapted to a wide range of conditions is shown by their general use. In drilling for water, oil, and gas they have been successfully employed in every part of the United States, and in drilling for water they are used in nearly every country in the world.

PERCUSSION CORE DRILL.

Within the last few years a percussion core drill, designed to obtain a core when prospecting coal and other relatively soft deposits (see p. 30), has been put on the market by a manufacturer of portable drilling machines. This drill is substituted for the ordinary drill after the hole has been sunk nearly to the material of which a sample is desired.

The drill consists essentially of a hollow tube or bit stem armed with a toothed cutting bit, a core barrel, and a weighting bar. The teeth of the bit are " set " alternately in and out, like those of a hand saw, so as to give clearance to the drill on the outside and to the core within. The core barrel is a tube, about 4 feet long, that slides within the bit stem. It has a split ring near the bottom, which grips the core when the tools are withdrawn. As sinking progresses a weighting bar forces the core barrel down over the core and protects it from abrasion. (See fig. 10.)

The chief advantages claimed for the attachment are its adaptability to the ordinary portable drilling outfit; the large core yielded, as the device is made chiefly for 5⅝ or 6 inch tools; the ease and rapidity of withdrawing tools, as they are on a cable, not on jointed rods; and special adaptation to taking samples of very soft material. It is not intended for work in very hard rock nor in localities difficult of access.

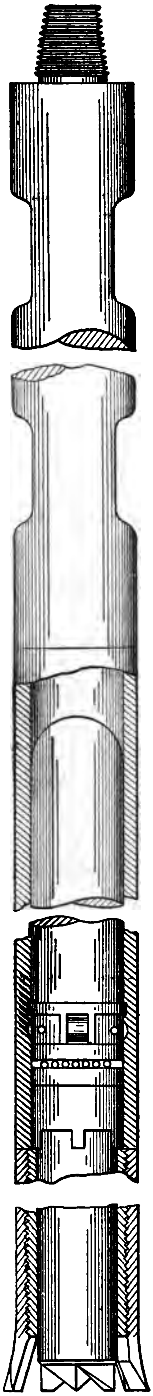


FIG. 10.—Percussion core drill.

POLE-TOOL METHOD.

GENERAL FEATURES.

The pole-tool or wood-rod method of well drilling is old and, in some respects, rather primitive, representing an early stage in the development of churn drilling. It differs from the standard method chiefly in using wooden rods instead of a cable for operating the tools.

Previous to the introduction of hemp cable the pole-tool outfit was much used in England and France, where it is still employed to some extent; but in the United States it has been largely superseded by cable rigs. It is, however, still used in this country for sinking water wells in certain regions, especially in the area between Illinois and Montana and north of Kansas and Colorado, where the great depth of the wells and the large amount of water encountered make the retention of wood rods advantageous in drilling wet holes. If a portion of the hole is drilled dry, a cable is attached and drilling is conducted as with the standard outfit; but the friction of 1,200 or 1,500 feet of hemp rope in as many feet of water so greatly reduces the force of the blow on the rock that a pole-tool outfit may be more advantageous.

When a cable rig is used in a hole containing considerable water the friction may be reduced by tarring or oiling the rope so that the fibers can not spread. This treatment, however, affords only a temporary remedy and but slightly decreases the friction of the rope. By using wooden rods the friction is greatly reduced, and the drill can be operated much more efficiently.

In the oil and gas fields of Pennsylvania and Ohio it is desirable and often necessary to keep water out of the hole, either because the operator can drill faster in a dry hole or because he must exclude water from the oil sands; but in North and South Dakota, Wisconsin, and Illinois, where the pole-tool outfit is in use, the driller is drilling for water and may desire to retain all flows he may pass to supply the completed well. A cable rig could be satisfactorily used only by casing out the water, drilling the hole to the depth necessary to guarantee a sufficient supply, and then drawing the casing or perforating it to allow the water access to the well. Experience has shown that under ordinary conditions the expense of the casing and of the increased labor required in drawing or perforating it, when drilling water wells with the standard outfit, exceeds the cost of drilling with the pole-tool outfit, in spite of the extra labor involved in the actual drilling with the latter.

The necessity of maintaining the initial diameter of the rods prevents drilling a hole as small as that which can be drilled by means of a cable. If the hole is full of water and its size is decreased to 3 or 4 inches, drilling is greatly impeded by the long column of water that rises and falls with each stroke of the drill. The diameter of the hole, therefore, can not be reduced below the size which gives ample clearance between the rods and the well wall. In the pole-tool method the drill falls on the rock at the bottom of the hole as a dead weight, and a springing blow can not be struck as when drilling with a cable. This reduces the speed of drilling considerably.

OUTFIT.

A derrick about 60 feet high and 16 feet square at the base is used with the pole-tool outfit. It resembles the standard derrick in most respects and requires about ten days to set up and two to four days to take down.

The string of tools of the pole-tool outfit, like that used with cable outfits, consists of socket, jars, auger stem, and drilling bit. The rods, which are substituted for the rope, are 2 to 3 inches in diameter. Each length of rod consists of two 18-foot pieces, spliced together and reinforced at the joint by irons. (See fig. 11, *C*.)

Jars are used to prevent the weight of the rods from coming on the drill, and also to prevent the crushing of the rods under their own weight. Before the invention of jars this battering and crushing was a constant source of trouble in well drilling with rods, and was the chief cause of the numberless fishing operations of early days. The jars, therefore, can not be discarded from pole-tool outfits as they sometimes are from cable outfits.

As with the standard outfit a walking beam is used, and the length of stroke is controlled by changing the length of the crank; but a ratchet on the walking beam, operated by a crank and lever within easy reach of the driller is used instead of a temper screw for feeding the drill. (See fig. 11, *A*.) A chain runs from the drum of the ratchet over the end of the walking beam and is connected with the rods by means of a swivel.

DRILLING OPERATIONS.

While drilling, the tools are constantly rotated so as to keep the joints on the rods tight and the drill hole round, for there is not sufficient natural torsion in the rods, as there is in a cable, to keep the drill from striking twice in the same place.

In drawing the rods, the whole string is raised by means of a hemp cable with swivel attachment, operated through a pulley at the top of the derrick. When the first joint appears above the top of the well head an assistant sets the square end of the joint iron into a wrench laid in the socket of the wrench block. (See fig. 11, *B*.) The wrench tightly fits this socket in the block and is prevented from turning when the rods are turned by a small iron post, the arrangement serving the function of the wrench and floor circle used in the standard outfit. With another wrench a second workman unscrews the swivel by which the raising cable has been attached to the upper rod, and this rod is unscrewed from the one below and set at one side of the derrick. The wrench that is fitted on the square end of the second rod previous to detaching the first length prevents the whole string of rods and tools from dropping into the bottom of the well when the first length is removed. The swivel is then lowered and screwed to the upper end of the second length of the rods. These are drawn up so that the square joint iron of the third length fits into the wrench, and the whole string of rods and tools is held by it while the second joint is being unscrewed. In the same manner the entire string of rods is raised and taken apart. This operation makes it necessary for one workman to be in the derrick about 36 feet above the surface of the ground, but in this position he is able to help the man at the well head in steadying the rods and setting them to one side, and in guiding the descent of the lifting swivel.

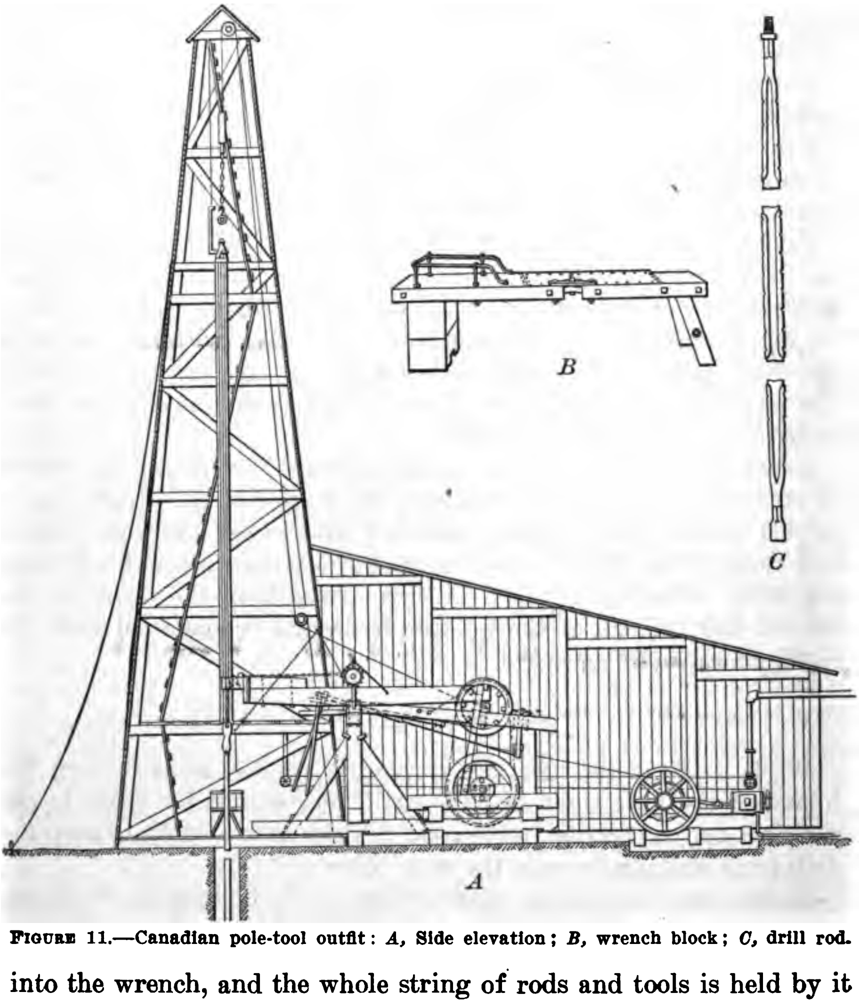


FIGURE 11.—Canadian pole-tool outfit: *A*, Side elevation; *B*, wrench block; *C*, drill rod.

In raising and lowering the tools the men work rapidly, though two of the three men needed in operating the outfit are busy only during the time that the drill or bailer is being raised or lowered. There appears to be great waste of time in this method of drilling, especially in bailing the cuttings, for which purpose a steel cable might well be used when the drillings are thin, as the bailer can be made of a size and weight to cause it to sink to the bottom of the well without difficulty. At least an hour is spent in raising the drill out of the hole, lowering the bailer, redrawing it, and resuming operations with the drill. Each one of these four operations involves the unscrewing and screwing up of rods in 36-foot lengths, and in a hole 1,000 or 1,500 feet deep the labor required is very great. Expert drillers can raise and lower the rods at the rate of 100 feet a minute, and ordinary workmen at the rate of 60 to 75 feet a minute.

In drilling some wells bailing does not occupy so large a part of the time. In artesian wells, for example, the cuttings may be carried away by the pressure of the water. The head at shallow depths may, however, be insufficient to accomplish this, but it may be greatly increased when the hole is deepened to coarser water-bearing material, and bailing may then be discontinued. In creviced rocks the drillings may be carried off by the downward and outward movement of the water.

When lowering the rods into the drill hole care should be taken to keep the lowest joint—that connecting the rods with the jars—looser than any of the other joints of the string, so that if the drill sticks fast in the rock the driller may unscrew the rods and remove them from the hole without difficulty.

The drill may then be loosened by a fishing spud and the rods lowered into the hole, fastened to the pin of the jars, and the tools withdrawn. Occasionally, however, the lowermost joint becomes tight, especially when drilling in rocks of irregular structure or rocks in which there are many crevices. In an accident following such a tightening of the rods on the drill it is sometimes necessary to lower a knife into the well and cut away the rods just above the drill. Then, after the tools have been spudded loose, they may be withdrawn by a slip socket.

Loss of tools—the most common accident in using pole-tool outfits—is due to failure of the man at the well head to catch the square shoulder at the end of the rod with his wrench, as a result of which the tools drop to the bottom of the well. The rods are usually broken by this accident and have to be removed piece by piece by means of spears, slip sockets, and other devices. Sometimes the buckling and breaking of the rods in the hole prevents their withdrawal and the hole must be abandoned.

A drill in a well in which the driller desires the water to enter from all parts of the hole may encounter caving rock between two water-bearing beds. An attempt to shut off the caving rock by casing from the surface to the rock would shut out the water above it or would necessitate perforating the casing at the level of the upper water. Caving is therefore prevented by lowering into the well a piece of casing long enough to cover the caving rock. The hole is then reduced in size and drilling is continued. In the vicinity of Chicago caving rock is found at a depth of about 1,000 feet. It does not usually carry much water and the little it contains is under slight head. The short piece of pipe, therefore, stops the inflow of material and allows drilling to proceed.

Where a pole-tool outfit encounters quicksands it is almost worthless because of the great amount of time required in withdrawing the tools and the rapid inflow of the sand, and it must therefore be supplemented by rotary appliances.

SELF-CLEANING OR HOLLOW-ROD METHOD.

OUTFIT.

The self-cleaning or hollow-rod method of well sinking includes the essential features of the percussion methods, but differs in combining in one operation the breaking up and removal of the material.

The tools consist of a string of pipe with screwed couplings, usually of special manufacture to insure strength and durability, with a water swivel at the upper end and a drill bit at the lower end. Because of this use of joints of pipe instead of a drilling cable the machine is often called the hollow-rod outfit.

The water swivel is essentially a swiveled gooseneck that allows the water and drillings to be discharged from the pipe in a constant direction and still permits the drill pipe to be rotated. In the usual outfits of this class the pipe is 1½ or 2 inches in diameter and the drill is 2½ to 4 inches across, though the hole may be enlarged by using an expansion bit.

The drill bit has one or more holes at its upper end and a flap valve that allows water and drillings to enter the pipe and be lifted automatically to the surface. Blind valves are also usually placed at intervals within the pipe to relieve the lower valve of the weight of the entire column of water and drillings.

The outfit usually includes a mast that is held upright by guy lines and supports a sheave pulley over which passes the cable used in operating the tools. In many of the outfits the device for lifting and dropping the tools consists simply of a pulley and reel. The cable is fastened to the upper end of the string of hollow rods, passed over the sheave pulley, and one or two turns are taken around a hoisting reel. As the reel is continuously revolved by engine or other suitable power the drill may be raised and let drop by alternately tightening and loosening the rope on the reel. Self-cleaning tools are also commonly used with portable rigs, being operated by the spudding attachment.

The "Ohio" machine is a self-cleaning outfit that has been fitted with a special operating device. In this outfit the rods are gripped by jaws and lifted by power transmitted through a crank and pitman. At the upper end of the stroke levers attached to the jaws are tripped, the tools are released and fall freely, and are caught up again by the jaws, on the rebound of the blow.

DRILLING OPERATIONS.

In drilling by the self-cleaning method water must occasionally be poured into the well until it is encountered in sufficient quantity for the needs of drilling. The drilling operation is continuous, for as the drill is alternately raised and let fall the jumping or pumping action forces water and drillings into the drill rods and upward to the surface. This action resembles that of a hydraulic ram, but in the drill the sudden compression required to open the valve is obtained by the drop of the tools instead of by the fall of a water column, as in the ram.

The efficiency of the pumping action of the drill depends on the shape of the drill shoulder, which for best results should have a circular cross section a little smaller in diameter than the width of the flat cutting edge, from which it should flare outward sharply so as to obtain the greatest effects of compression in opening the valves and forcing the drillings upward.

The pipe is slowly rotated during drilling, so that the drill will not strike twice in the same place and so that it will spall the rock off in flakes and not break the material simply by striking a straight blow. Ordinary casing with screw couplings is commonly used to case off caving material and excessive water, and is sunk as drilling progresses by a drive weight attached to the drill rods, whose weight is thus made to aid in the driving.

A properly tempered bit will be sharper when it is taken out of the hole than when put in, for the wear comes mainly on its edge and tends to reduce its gauge. When the approximate depth of the hole to be drilled is known, bits may be run long distances. So long as they are larger than the joints on the rods they will not stick as will cable bits when worn, for the vibration of the rods keeps them free. Many holes 100 to 150 feet in depth have been drilled with one bit without removing it from the hole. When a bit is used too long, however, the hole must be reamed when a bit of standard gauge is substituted for it.

USES.

The self-cleaning outfit is admirably adapted to sinking water wells of small diameter in sand, clay, shale, soft limestone, and other easily penetrated materials. Concerning its use for this purpose, Veatch says:[a]

> The important feature of this rig from a water standpoint and the one which makes it of peculiar utility for sinking water wells in the Coastal Plain region is that it is impossible to pass a water-bearing stratum, no matter how small, without being aware of its presence.

The self-cleaning drill is also used extensively in prospecting for coal in Ohio and for lead and zinc in Wisconsin and Illinois. In coal prospecting a solid drill and cable are often used in drilling much of the distance down to the coal bed, and the self-cleaning tools are then used to determine the thickness of the bed. A larger bit than common is usually employed for this purpose, as it takes larger and more determinative samples. The casing can be easily withdrawn from prospect holes by driving it upward.

CALIFORNIA OR STOVEPIPE METHOD.

INTRODUCTION.

For sinking water wells in the unconsolidated alluvial deposits of portions of California a method is used which, on account of its distinctive character, is called the California or stovepipe method. It is also sometimes called the mud-scow method, because of the instrument by which drilling and bailing are accomplished.

The following description is adapted from two articles by C. S. Slichter[b] and by I. N. Knapp.[c]

RIG.

The rig consists of a horizontal rectangular frame to which is hinged a derrick about 34 feet high, held vertical by two diagonal braces from the frame to the derrick. The walking beam—a marked feature of this rig—is carried at the top of the derrick. The bottom of the derrick is hinged to a saddle piece resting on two coiled car springs, which in turn rest on a heavy crosspiece bolted between the sides of the frame.

The hoisting reel and other machinery are placed on the framework just back of the derrick, and at the farther end are the engine

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[a] Veatch, A. C., Geology and underground-water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 101.

[b] Slichter, Chas. S., Field measurements of the rate of movement of underground water: Water-Supply Paper U. S. Geol. Survey No. 140, 1905, pp. 98–103.

[c] Knapp, I. N., Drilling wells in soft and unconsolidated formations: Stevens Inst. Indicator, vol. 22, 1905, pp. 17–30.

and hydraulic pumps. When steam power is used, the boiler is separate and is placed at one side, near the engine. When the machine is to be moved, the mast is swung back on its hinges, with its top resting on an upright at the rear end of the rig. Jackscrews are then placed under the sills and the whole machine is raised sufficiently to allow wheels to be slipped onto axles bolted to the sills.

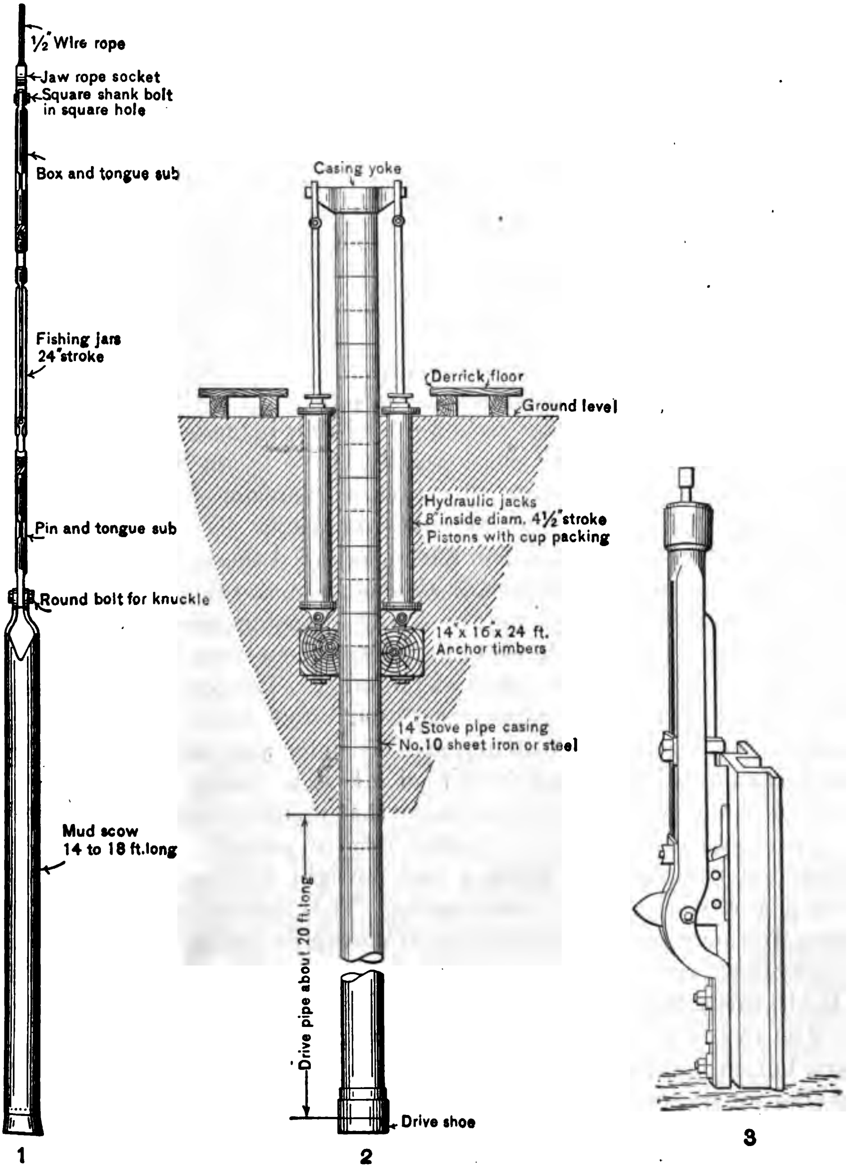

FIGURE 12.—Parts of California or "stovepipe" outfit. 1, String of tools; 2, casing, drive shoe, etc.; 3, perforator for slitting stovepipe casing.

In drilling, the walking beam is given a reciprocating motion by a wooden rod attached to its rear end and to the driving machinery. The tools are suspended from its forward end by a cable, usually a half-inch wire rope. The string of tools below the socket by which it is attached to the cable consists of a box and tongue sub, to which is screwed a pair of jars of the usual type, and below the jars is another sub to which is fastened the sand bucket or mud scow. (See fig. 12^1.) The sand bucket is similar in shape to that used with the standard outfit, and has a flap valve at the bottom, like that of the standard sand bucket; but it differs in being connected to the tools above by a knuckle joint that permits easy dumping, instead of by a bail, and at the bottom it carries a cutting shoe similar to that used on the bottom of a string of casing. For drilling in clay this shoe may be modified by a straight chisel-like bit extending as a diameter across it.

CASING.

The casing used in this method of drilling is made of lap-riveted cylinders of sheet iron or steel, usually of No. 10 to No. 14 gage, 24 inches long and 6 to 14 or 16 inches in diameter. (See fig. 12^2.) These short joints are known as stovepipe casing. The pieces of sheet metal may be taken to the field flat and riveted there, but usually the riveting is done at the shops and the ends are also turned square and true. Two sizes are used for the string of casing, one of which just slips within the other, so that the joints of one may be adjusted to fall midway between the joints of the other. The sections are added one at a time as sinking proceeds, each 2-foot joint adding only 1 foot to the length of the string, and the outer and inner sections are united simply by denting with a pick. This casing is water-tight, but for water wells it is not necessary that it should be.

Stovepipe casing may be started from a properly recessed drive shoe, but it is easier to begin a well straight and keep it plumb by using a starter, as with other casing. This starter is 15 or 20 feet long and may be made of sections of stovepipe casing, often of three thicknesses, riveted together, or of a joint of heavy lap-weld casing. At the lower end is an annular steel drive shoe. (See fig. 12^2.)

The casing is usually sunk by two or more hydraulic jacks which are buried in the ground and anchored to two timbers, about 14 inches square and 16 feet long, planked over and buried 8 or 10 feet deep. In the smaller sizes of shallower wells the casing is sometimes forced down by two steel I-beams or railroad rails, arranged as powerful levers.

DRILLING OPERATIONS.

After the outfit has been set up and the starter and hydraulic jacks have been sunk in position, the string of tools is lowered and drilling begins. In this process the sand bucket or mud scow, as it is worked up and down by the walking beam, acts both as a drill and a bailer. In ordinary material it is rotated to loosen the sand and gravel from inside of the casing, and when it is drawn up to be emptied the bucket is manipulated in such a way that the weight of the jars and connections assist in the dumping.

The driller stands at the front of the rig and has complete control of the engine, hydraulic pump, jacks, and clutches that cause the tools to work up and down or be hoisted.

Water is necessary for the drilling operation, and must be added at the top of the casing until it is struck in the hole. The sand bucket must not be run until it is filled to overflowing, for the excavated material may spill over between the bucket and the casing and stones and gravel may become jammed between them and cause a serious fishing job. Bowlders that lie in the way are usually worked to one side of the casing shoe and passed by, by drilling on them with the bucket, which takes up the finer material; or if the bowlders are unusually difficult to pass, they are broken to pieces by a drill that is substituted for the sand bucket.

In drilling in quicksand or caving ground it is necessary to keep the water level about the same inside the casing as on the outside, and also to keep the casing even with or ahead of the excavation made by the bucket. In very soft ground a hole larger than the casing is apt to form, thus making a cavity outside of the casing, and falling ground from the top of such a cavity is liable to crush the casing.

PERFORATION OF CASING.

A record of the material encountered in sinking the well is kept, and after the well has been sunk to the required depth a cutting knife is lowered into it, and vertical slits are cut in the casing at such water-bearing strata as may be most advantageously drawn upon. A well 500 feet deep may have 400 feet of screen—that is, perforated casing—if the circumstances justify it.

One style of perforator for slitting stovepipe casing is shown in figure 12^3, the perforator being shown in cutting position with knife extended. It is handled with a 2-inch standard pipe with ¾-inch standard pipe inside. In going down and in coming out of the well the weight of the ¾-inch line of pipe holds the point of the knife up. When ready to "stick" the ¾-inch line is raised; then by raising slowly on the 2-inch line with the hydraulic jacks, cuts are made three-eighths of an inch wide and 6 to 12 inches long, according to the material at that particular depth. Another style of perforating knife has a revolving cutter that punches five holes at each revolution of the wheel. This kind of perforator is called a "rolling knife."

ADVANTAGES.

The advantages of the California method of well construction for use in unconsolidated deposits have been summarized by Slichter as follows:[a]

1. The absence of screw joints liable to break and give out.

2. The flush outer surface of the casing, without couplings to catch on bowlders or hang in clay.

3. The elastic character of the casing, permitting it to adjust itself in direction and otherwise to dangerous stresses, to obstacles, etc.

4. The absence of screen or perforation in any part of the casing when first put down, permitting the easy use of sand pump and the penetration of quicksand, etc., without loss of well.

5. The cheapness of large-size casings because made of riveted sheet steel.

6. The advantage of short sections, permitting use of hydraulic jacks in forcing into the ground.

7. The ability to perforate the casing at any level at pleasure is a decided advantage over other construction. Deep wells with much screen may thus be heavily drawn upon with little loss of suction head.

8. The character of the perforations made by the cutting knife are the best possible for the delivery of water and avoidance of clogging. The large side of the perforation is inward, so that the casing is not likely to clog with silt and débris.

9. The large size of casing possible in this system permits a well to be put down in bowlder wash where a common well could not possibly be driven.

10. The uniform pressure exerted by the hydraulic jacks is a great advantage in safety and in convenience and speed over any system that relies on the driving of the casing by a weight or ram.

11. The cost of construction is kept at a minimum by the limited amount of labor required to man the rig as well as by the good rate of progress possible in what would be considered in many places impossible material to drive in, and by the cheap form of casing.

HYDRAULIC ROTARY METHOD.

DEVELOPMENT.

The hydraulic rotary method of drilling has been used for many years for sinking shallow water wells in fine-textured, unconsolidated materials, but it attained prominence in deep-well drilling in 1901, when it was first successfully used in sinking oil wells in the Spindle Top field near Beaumont, Tex., where other methods of drilling had failed, and it has since been a great factor in the development of the Texas fields. Its successful use in that region and the consequent great improvement in the machinery employed has led to its increasing use where soft materials are encountered. Sinking is accomplished by the rotation of an annular toothed shoe on the bottom of the string of casing.

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[a] Water-Supply Paper U. S. Geol. Survey No. 140, p. 101.

OUTFIT.

With the hydraulic rotary outfit a derrick similar to that of the standard rig is used, but the machinery and tools are unlike those of percussion outfits. The principal parts of the machinery are a revolving table or whirler, two hydraulic pumps, and boiler, engine, and line shaft to furnish power.

The revolving table is a heavy rotating device, set on tool-steel rollers, that grips the casing firmly and permits it to be revolved and yet allows it to be gradually lowered as sinking progresses. The table is revolved by means of bevel gearing connected with the line shaft and controlled by a clutch and lever.

The hydraulic pumps, which supply water for drilling, are capable of developing a pressure of 125 to 175 pounds to the square inch. As the water used is very muddy the pumps are made with but 6 to 10 valves, whereas if the water were clear 20 to 24 valves would be used. The valves also fit more loosely than in ordinary pumps, so as to reduce the abrasion produced by the sediment. Only one pump at a time is in use, but to permit packing of the valves and to provide for accidents and emergencies two pumps are always installed. In many plants two boilers are also installed for similar reasons. The pump that is in use is connected with the top of the casing through a hose line and water swivel similar to those in the self-cleaning outfit, but larger, so as to allow the continuous pumping of water into the casing while the latter is being rotated. A back-pressure valve is usually inserted in the gooseneck at the upper end of the swivel, to relieve pressure on the hose. Two swivels are needed, one being attached to the joint of casing to be next added to the string, while the other is in use.

The engine is connected by a link drive chain to the line shaft, which also furnishes power to the revolving table and to a hoisting drum and reel.

Thin mud or slush plays an important part in drilling, and a slush pit is an essential accessory of the outfit. This pit is usually dug near the derrick, on the same side as the pumps, and is about 40 feet long, 15 feet wide, and 3 or 4 feet deep, though the size varies with convenience and the preference of the driller. A ditch where sand may settle out of the mud is cut from the well circuitously to the slush pit, from which hose or pipes lead to the pumps. (See fig. 13.)

DRILLING OPERATIONS.

Drilling is accomplished by rotating the entire string of casing, on whose lower end is a toothed cutting shoe. The rotation under heavy pressure breaks off and grinds up particles of the material that

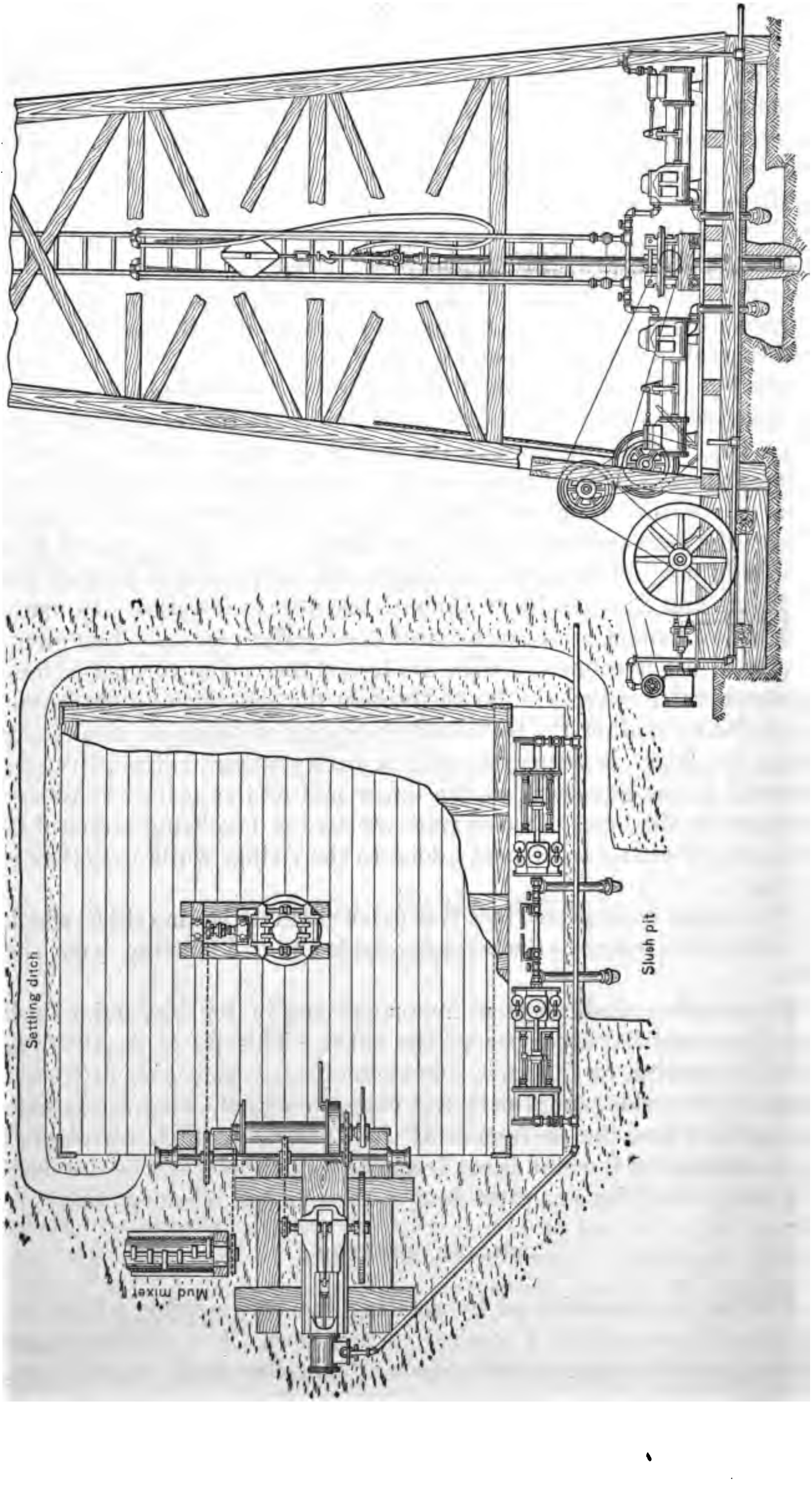


FIGURE 13.—Hydraulic rotary outfit; plan and elevation.

is being penetrated, and they are carried to the surface by water that is pumped down the casing under pressure and rises on the outside, between the casing and wall of the hole. Only one casing, that which is being revolved, is used, for as the muddy water escapes upward it puddles the side of the well so that the material stands alone.

If a bed of clay is encountered, the water used in drilling is kept as clear as possible and is not drawn from the slush pit, for the clearer the water is when introduced the greater is its capacity to uphold and move particles of earth, and the clay is sufficiently compact to make a wall that will not cave. In penetrating sand and gravel layers, clay often has to be added to the slush pit, so as to make a thin mud that will plaster up these beds and prevent them from caving and also prevent the escape of drill water into them. In some oil fields a trough with revolving paddles, called a mud mixer, is used to prepare the slush of proper consistency for plastering up sandy layers and also for closing gas pockets.

A pressure gage enables the driller to feed the casing into the hole with uniform pressure. The casing must be lowered with care, for if it is fed too fast the hole may become clogged by failure of the pumps to raise the outside column of water and carry up the drillings. Many clays are so compact and dry as to resist strongly the action of the water, and if the casing is fed too rapidly a core forms within it, reducing the size of the opening through which the water must pass, and correspondingly increasing the pressure exerted by the pumps. This difficulty may be obviated by fastening across the end of the rotary shoe a bar that will cut the core to pieces as rapidly as the shoe is fed into the clay.

When the casing has been sunk so that its top is near the revolving table, another length of casing to whose upper end the second water swivel is attached, is elevated by means of the hoisting reel so that it can be screwed onto the last length used. The first water swivel is then unscrewed, the new length of pipe is coupled on, and the hose connected to the water swivel at its upper end. This operation requires only a few seconds of the skillful workmen's time, and drilling proceeds with scarcely any interruption. To prevent the drenching of the men during the attachment of the water swivel, the pipe couplings are sometimes fitted with back-pressure valves.

It is essential that the pump be kept going constantly, otherwise the drillings will settle in the bottom of the hole and "freeze" the pipe fast. Should drilling cease at any time the water circulation must be kept up if possible, as slight cavings of material will cause the pipe to become clogged.

One size of casing is carried down until the friction of so much pipe against the wall of the hole renders its turning difficult, or it becomes "frozen," or stuck fast, from some other cause. A smaller size is then used until it in turn becomes fast. When it does become necessary to withdraw the rotary casing to change a shoe or put in a well casing, the driller always risks a caving hole where the wall is not protected by casing; but if the wall of the hole is thoroughly puddled the risk is not great, and often one may see drillers in the oil regions of Texas pull 700 or 800 feet of casing, the whole section of loose sands and clays standing unsupported.

SPECIAL OPERATIONS.

In penetrating firm material it is sometimes necessary to employ a rotary drill bit instead of the rotary shoe. Two styles of bit for this purpose are in general use—the diamond-shaped and the fishtail. The diamond-shaped is usually first employed, and the fishtail afterwards used for reaming or enlarging the hole. These bits are used on a smaller casing than that which is employed with the rotary shoe, and slip down inside the larger casing. In hard rock chilled shot or other abrasive may be used as in the shot method, described on page 86.

For fishing operations, which are sometimes rendered necessary by the twisting off of the casing, tools are used that do not differ greatly from those employed for similar purposes in percussion drilling. If the twisted-off portion is short, however, it may be possible to pass it by using a diamond-shaped bit and "sidetracking" or drilling past it.

On completing an oil well by the rotary method it is best to withdraw the casing and replace the toothed rotary shoe by an ordinary drive shoe, for it is difficult to make a water-tight joint at the bottom if the toothed shoe is left in the well. As in the percussion methods of oil-well drilling, the drive shoe is usually set in the formation that is known from other wells in the same locality to overlie the oil-bearing sands. Drilling is then continued inside the casing for the remaining few feet or yards to the oil sands, and a smaller string of casing with a strainer at the bottom is lowered to the oil.

Packing is accomplished, as in other methods of drilling, by seed bags, cement, or special packers. A packer called a boot leg is also frequently used. This is a slightly tapering leather sleeve somewhat larger than the casing. It is slipped over the casing and its lower (smaller) end is tied fast to the casing a short distance above the strainer. The mud remaining about the casing settles into the open upper end of the boot leg and thus fills and packs the space between the casing and the side of the hole.

Many water wells sunk by the hydraulic rotary method are difficult to screen because of the depth at which the operation is conducted and the fineness of the material. A method in use is to puddle the wall of the well at the water-bearing layer, set the screen, and draw the casing to the top of the screen. By pumping heavily for a few hours the pores of the puddled water-bearing sand are partly reopened, but the method has the defect of leaving the water-bearing layers more or less clogged by fine material. A more difficult but a better and more common way of screening is to sink the screen below the casing by forcing a hole down by a jet of water, the wash pipe being run ahead of it. A packer or lead seal is then inserted at the point where the top of the screen joins the well casing to prevent material from rising over the top of the screen and filling it.

ADVANTAGES AND DISADVANTAGES.

An objection to the hydraulic rotary method for drilling water wells has been made by some engineers, who claim that the driller often seals off water by puddling, and that the location of the water-bearing stratum must be known before drilling begins, otherwise it will be passed through without the driller being aware of its presence. But operators of hydraulic rotary outfits claim that it is very easy to tell when a water-bearing layer is reached, as the gage shows a sudden decrease of pressure. This is true if the head of the water encountered is considerably beneath the level of the surface, but if the head is close to the surface—that is, if the water is nearly if not quite artesian in the sense that it will flow at the surface—the pressure will remain nearly the same and it will be impossible to tell that a water-bearing layer has been encountered.

The hydraulic rotary method is very rapid for drilling in loose material where the drill may descend continually. At Corsicana, Tex., 1,065 feet were drilled through clay and marl in thirty-two hours. Both method and machinery have been rapidly developed through extensive use in the Texas oil fields, and as the method becomes better known it bids fair to supplant others in use for lighter jobs. The method will, however, never supplant the jetting and self-cleaning methods for shallow work where only a cheap, light rig is required, any more than the heavy standard oil-well outfit will supplant portable rigs for drilling shallow wells; but for wells about 1,000 feet deep, in soft, fine-grained materials, it will in time be almost exclusively employed, especially as the number of drillers who understand its operation is rapidly increasing.

JETTING METHOD.

OUTFIT.

In the jetting method of well sinking the material is both loosened and carried to the surface by water under pressure.

The principal parts of the outfit are a force pump and water swivel, drill pipe, nozzle or drill bit, casing and drive weight.

Hand-power jetting outfits are made in several styles which differ chiefly in the arrangement for driving the casing. One outfit uses a block and tackle for raising and letting drop a weight of 200 pounds or more; another uses a lighter weight which is lifted directly by hand. Some outfits require a light derrick and working platform; others are operated from the ground. In a light hand-power rig like that shown in figure 14 the casing is about 2½ inches in diameter and the drill pipe about 1 inch. The larger machines have a mast and hoisting sheave and use engine power for handling the casing and drive weight and for working the pump.

DRILLING OPERATIONS.

In the jetting method water is led into the well through a pipe of relatively small diameter and forced downward through the drill bit against the bottom of the hole. The stream of water loosens the material and the finer portion is carried upward and out of the hole by the ascending water current, as in the hydraulic rotary method. During drilling the drill pipe is turned slowly to insure a straight hole.

Casing is usually sunk as fast as drilling proceeds. In the softer materials, by using a paddy or expansion drill (fig. 14^{4a-4b}) a hole may be made somewhat larger than the casing, which may be lowered a considerable distance by its own weight. Ordinarily, however, a drive weight is necessary to force it down. As a rule one size of casing may be employed for the entire depth of the well. It is usually difficult to drive a single string of casing beyond 500 or 600 feet by this method, and if the well is sunk much deeper, a smaller size must be used. In fine-textured, clayey or loamy material the hole may often be jetted down to the full depth required and the casing inserted afterwards, for the wall of the hole becomes puddled by the muddy water and the vibration of the drill pipe against it, so that it will stand alone, like the wall of a well drilled by the hydraulic rotary method.

When drilling with a light rig, hard layers may be penetrated by using a drill bit on the drill pipe, and raising and dropping the pipe so as to strike blows as in the percussion methods. In this operation a blind valve is usually inserted in the drill pipe near its bottom to prevent drillings from entering and clogging the pipe. With a heavier rig, equipped with mast and hoisting sheave, a cable and small drill may be used for penetrating locally hardened layers that do not readily yield to the water jet.

USES.

The jetting method affords a rapid and cheap means of sinking small water wells in comparatively fine-grained, unconsolidated ma-

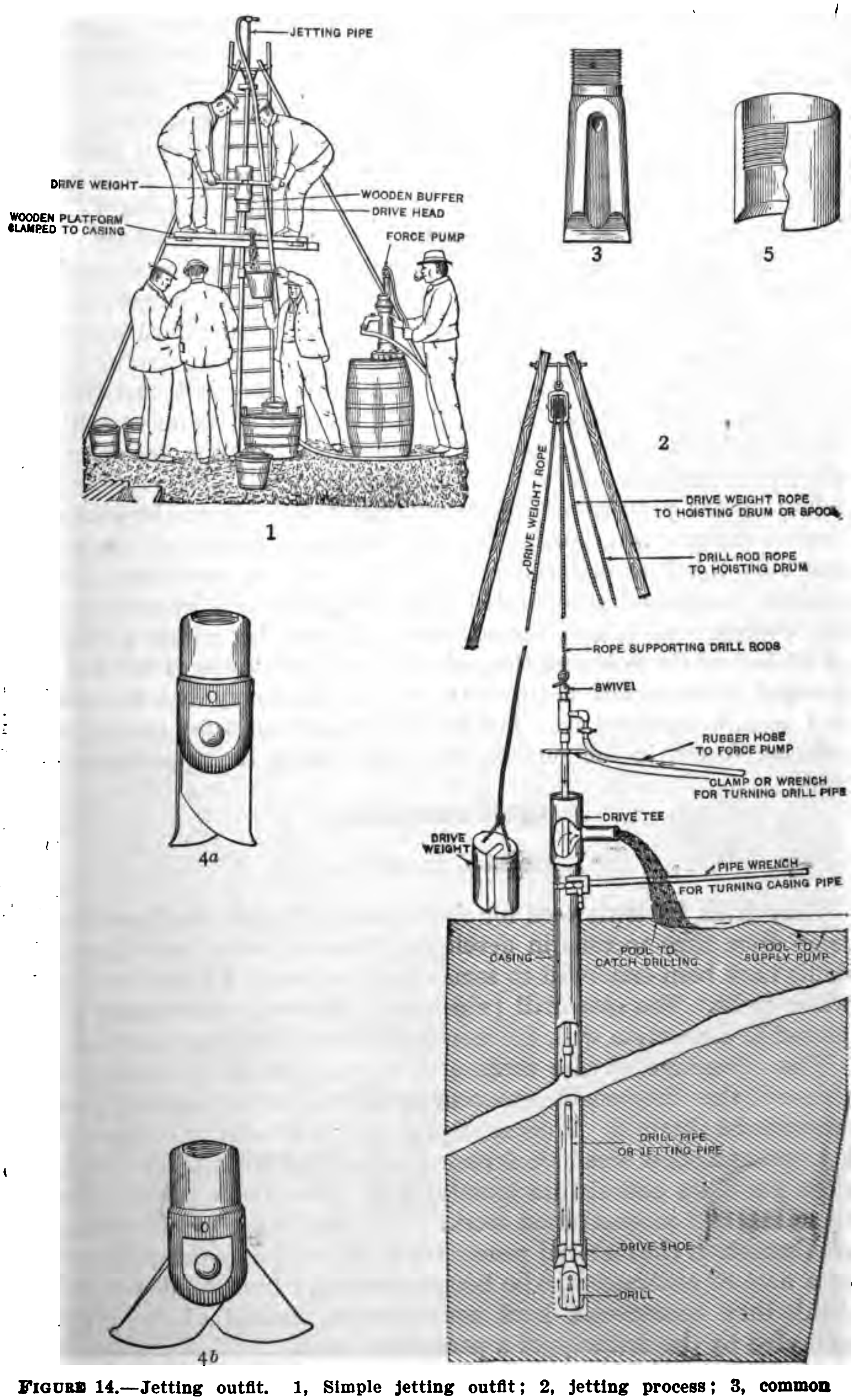


FIGURE 14.—Jetting outfit. 1, Simple jetting outfit; 2, jetting process; 3, common jetting drill; 4^{a},^{b}, paddy or expansion drills; 5, drive shoe.

terials and has the advantage of being easily taken from place to place. A fundamental disadvantage is that the nozzle or bit requires considerable water for its operation, and in some localities this requirement is a serious obstacle to the use of the method.

The jetting method is much employed for putting down wells in the Atlantic Coastal Plain and in some of the valleys of the arid West that are deeply filled with alluvium. In the Coachella Valley in southeastern California the method has been very successfully used in sinking wells for flowing artesian water. Most of the wells in this region are 400 to 500 feet deep and about 4 inches in diameter, and not uncommonly a well may be sunk, cased, and cleaned in two days.

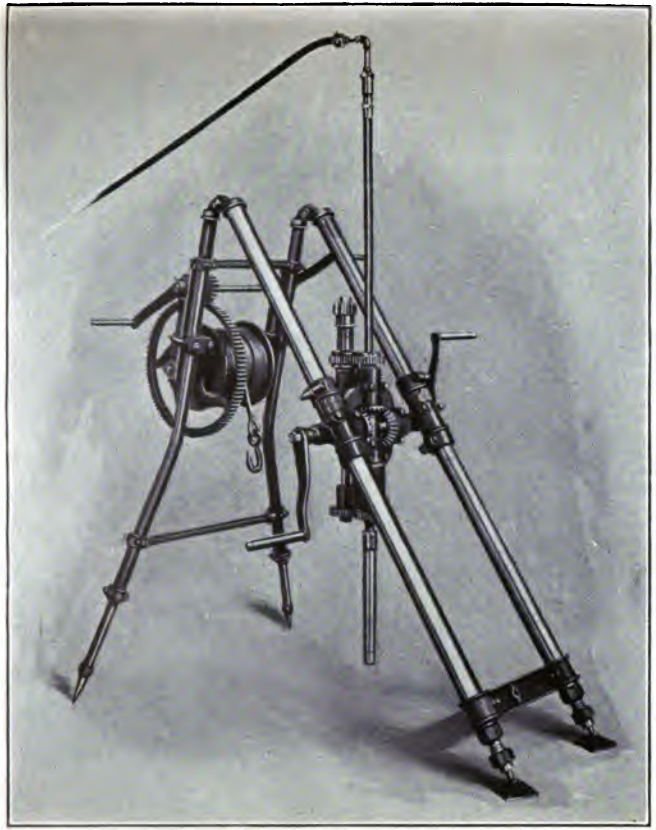
The method is also used in a few localities in mining kaolin. An iron pipe, 4 inches in diameter, is sunk to the clay bed, and inside this pipe a 1½-inch pipe, having a drill attached to its lower end, is inserted. A stream of water is forced down the pipe, loosens the clay, and forces it up between the smaller and larger pipes. By adjusting the pressure of the descending water column the coarser, impure materials in the clay bed are left in the bottom of the well, and only the finer material comes to the top. A very sharp fine-grained white sand is separated from the kaolin as a by-product in the washing and is used for masonry. All the clay within a radius of 40 feet of the hole and through the entire thickness of the bed is pumped to the surface in this way, and the pipes may then be pulled and used in another hole. The kaolin forms about 5 per cent of the solution forced to the surface, the fluid having the appearance of milk.

CORE DRILLING.

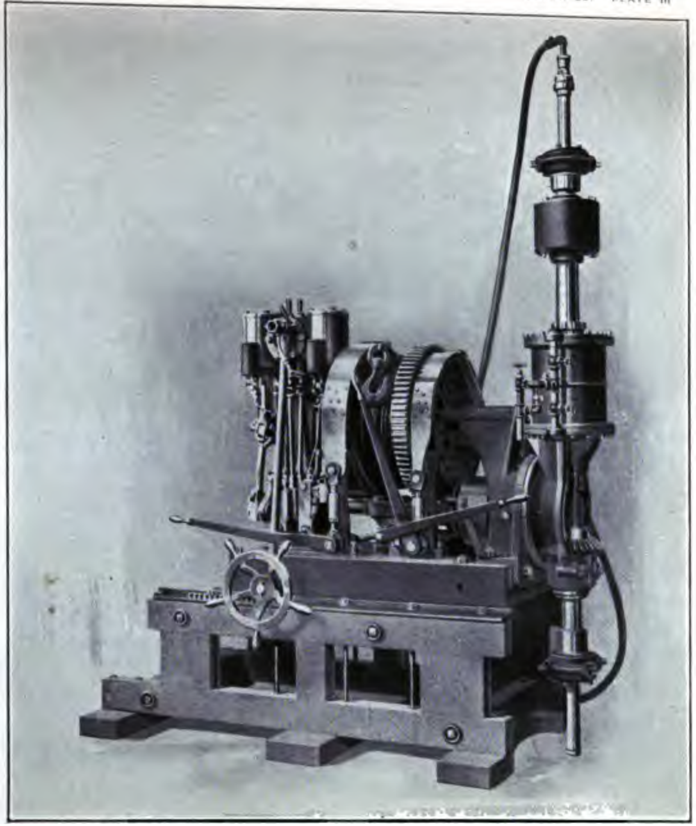
GENERAL FEATURES.

Core drills are little used for sinking wells, though they have been tried from time to time in developing new oil fields, and diamond drills have been employed to some extent in South Africa for deep-water wells. The core-drill principle is, however, occasionally employed in connection with the more common well-drilling outfits.

The advantage of core drills over all other types of boring machines is that they enable an accurate sample of the material penetrated to be obtained. They are therefore widely used in prospecting for coal and other economic deposits, for making borings for foundations for dams and similar structures, in preliminary tunnel investigations, and in excavation work. The importance of obtaining a true sample of the material penetrated is illustrated by the experience of a firm of contractors, who became bankrupt because at a certain depth they encountered hard conglomerate, instead of the gravel indicated by the drillings of a percussion outfit.



A. HAND-POWER DIAMOND DRILL, WITH FRICTION FEED.



B. STEAM-POWER DIAMOND DRILL, WITH HYDRAULIC FEED.

Rotary core drills of the several classes are alike in employing a hollow rotary drill that by abrasion wears an annular hole, leaving a core in the center. The drillings are removed continuously by water under pressure, and the core is broken off and removed from time to time.

Core drills are intended primarily for drilling holes of relatively small diameter in hard material. They resemble hydraulic rotary outfits in method of operation, but the formation of a core and the necessity for its occasional removal makes the drilling process intermittent instead of continuous.

Core drills may be used in all kinds of rock, from the hardest trap to the softest shale, but where a core is not especially desired drilling in the softer formations can usually be done more rapidly by means of percussion, hydraulic rotary, jetting, or some other method, and as a rule saving can also be effected in the cost of outfit. A percussion core drill is described on page 59.

DIAMOND DRILL.

OUTFIT.

Diamonds were first used in drilling rock in 1863 by Rudolph Leschot, a French civil engineer. For deep-well drilling they were first employed by M. C. Bullock, who sank a hole to a depth of 750 feet in Schuylkill County, Pa., to determine the existence and thickness of coal beds.

Diamond-drill machines (see Pl. III, *A*) to be worked by hand are made, but the larger outfits (Pl. III, *B*) require a derrick, hoisting sheave, and hoisting drum similar to those employed in other methods of drilling. The drilling apparatus includes a force pump and water swivel, drill rods, and rotating device for turning them, feed mechanism, and a cutting bit.

The derrick in most common use is a tripod from 20 to 80 feet high, the height varying with the work to be done. Where timber is easily available the derrick may be constructed of poles, but for drilling to depths of 1,000 feet or more a strongly braced 4-pole tower or a steel derrick is usually employed. The drill rods are smaller and lighter than those used with the hydraulic rotary outfit, and the hoisting drum, force pump, and water swivel, though similar, are correspondingly lighter and are of somewhat different design. Only one force pump is installed, as the danger of sticking if the water current is stopped is not so great as in the hydraulic rotary method. The drill rods are of heavy lap-welded iron tubing or of seamless steel tubing, with screw joints (fig. 15^{1-2}), and are 5 to 10 feet long. The sections are added as sinking progresses.

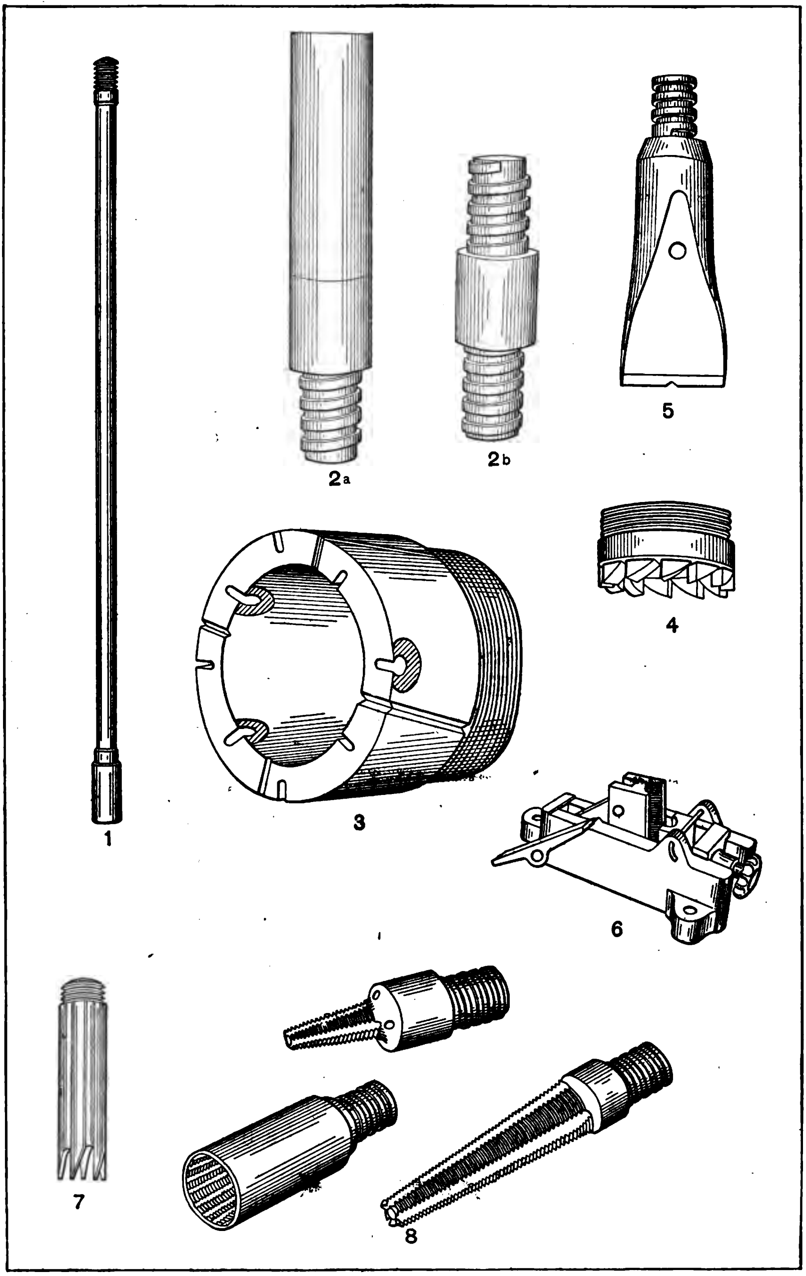


FIGURE 15.—Parts of core-drilling outfit. 1, Davis calyx drill rod with coupling attached; $2^{a,b}$, end of a drill rod and rod coupling; 3, bit to be set with diamonds; 4, toothed cutter bit; 5, chopping bit; 6, safety clamp; 7, toothed collar; 8, coupling recovery taps.

In nearly all diamond-drill outfits the drill rods are rotated by means of bevel gears. In the smaller machines connection with the power is made also by "tight" gearing, either chain or cog drive; but in the larger machine belt drive is used, so that the belt may slip if the drills become caught, as otherwise the rods may be twisted or broken.

As the total weight of the rods in a deep bore may reach 15 or 20 tons—a weight which would crush or break the diamonds—the rods must be supported and the drill must be fed into the rock slowly. Two feed devices—a differential feed and a hydraulic feed—are in general use, both designed to prevent the sudden and severe strain that would be brought upon the stones by drilling through soft and into hard rock with a positive feed—that is, a feed so regulated as to advance the drill rods equal distances in equal periods of time. In one style of differential feed used on many of the smaller diamond drills the drill rods are advanced by means of a frictional gear on the bottom of the feed shaft, which, by maintaining a uniform pressure on the drill, makes it sensitive to the character of the rock through which it is passing. A differential feed used on one style of calyx core drill advances the rods by a loop of rope which passes over a pressure yoke and is wound on two small drums.

In the hydraulic feed the forward motion is accomplished and regulated by means of hydraulic pressure which is applied through a cylinder and piston. The cylinder is connected to the pump which supplies water for drilling, and a pressure gauge indicates the amount of pressure on the bit. This device is under the immediate control of the operator, who regulates the feed by a small lever. The cylinder is so constructed that the water can not escape from its bottom faster than it enters at its top, and its lower part therefore always contains water. If a cavity is struck the drill rods hang on the piston, which is supported by the water, and as this is incompressible it prevents the rods from dropping into the cavity and the feed continues downward as regularly as if the drill were working in hard rock. Before the hydraulic feed was devised the diamond drill did not work satisfactorily in creviced rock because the drill and rods were apt to drop into cavities and thus break the diamonds.

The bit is made of a ring or sleeve of tough but ductile steel, three-eighths to five-eighths inch thick, whose upper end is threaded to screw into the drill rods and whose lower end is turned true and bored with eight holes to contain the diamonds. The diamonds are carefully set in the holes so that their lowest points lie in a plane, and are arranged alternately on the inner and outer faces of the bit, so that the outer edges of four project a little beyond the outer face and give it clearance, while the edges of the inner four project slightly beyond the inner face and clear the drill of the core. The diamonds are calked in place by carefully swaging the steel firmly against them with light blows. The old method of setting was to drill into the bit a hole about the size of the diamond, insert the diamond, fill around it with copper or other malleable metal, and swage the stone in firmly; but this method was troublesome and the diamond was often broken. In the latest styles of diamond drill bit the diamonds are set in steel nibs which are soldered or brazed into their places in the bits. When these nibs are used the expert diamond setter's services may be dispensed with.

Care must be taken that the bottom tips of the stones lie in a common horizontal plane and their outermost tips in the circumference of a circle; otherwise drilling will be done only by those diamonds that project downward or outward the farthest. This might result in drilling a hole of irregular shape and considerable inclination, or it might result in failure to drill at all. Grooves are cut across the face of the bit between the diamonds, and also on its outer side to permit the passage of drill water. A bit ready to be set with diamonds is shown in figure 15^8.

The shape of the bit and arrangement of the diamonds permit the stones to cut a path for the drill and slightly enlarge the cavity around it, and this clearance allows the drill to be easily lowered into the hole and also gives passage between the rods and wall of the hole for the drill water to convey the drillings to the surface. The stream of water also keeps the bit cool and prevents injury to the diamonds by heating.

Two kinds of diamonds, known as carbons and borts, are used in diamond-drill work. Carbons are found as opaque, irregularly shaped nodules, black on the outside and shades of gray on broken surfaces. They have no cleavage planes, and it is this quality, together with their hardness, which especially fits them for drilling in hard rock. Borts are semitransparent diamonds similar in appearance to the rough brilliant but differing in crystallization. They are usually nearly spherical in shape, are as hard as carbons but not as tough, and have a cleavage plane, so that when used in hard rock they may break; whereas carbons wear away but seldom break. Carbons come mainly from Brazil; borts from both Brazil and South Africa. Borts are much cheaper than carbons and may be used in boring in soft rock. In some holes a toothed cutter bit (fig. 15^4) similar to that of the hydraulic rotary outfit is used in penetrating soft rock. In moderately hard material a drill armed half with carbons and half with bort may be used, but for drilling in very hard rock only carbons are suitable.

The diamonds for a bit must be selected with special attention to uniformity of size and weight, as irregularity in this respect will disturb the balance of stones and necessitate frequent resetting. They usually require resetting after eight to twelve hours' work, so that two bits are needed, or, if running continuously, three are often employed, so that drilling need not be suspended while the stones are being set. The size of diamonds used for drilling ranges from about 1 to 4 carats, according to the size of the bit. Stones of approximately cubical shape are best, as they are stronger and furnish better cutting faces.

In the early drills the core was removed by means of gravel dropped down the rods. This became tightly wedged between the core and rotating barrel and caused the former to be broken off and held tightly so that it could be brought to the surface. In present forms of the drill a core lifter is placed in the barrel a short distance above the bit. Commonly this device consists essentially of a core barrel or shell and a split ring or sleeve. (See fig. 16.) The shell is bored with a slight taper downward, and within it the split ring is placed. This ring is usually wedge-shaped and often has inward projecting lugs to grip the core. Because of its tapering shape the ring is loose when in the upper part of the shell, but when it is pressed toward the bottom of the shell it becomes wedged under heavy compression and grips the core tightly. While the bit is in motion the ring does not rotate, but rides lightly on the core, sliding down over it as the bit advances into the rock. When the "run" has been made and the tools are hoisted, the raising of the shell compresses the ring and causes it to grip the core, thus breaking it off close to the bottom and bringing it to the surface. In a core barrel of this type the wash water is forced downward between the core and the barrel, and when penetrating soft materials, as coal beds, the water may disintegrate the core and render the sample imperfect. The barrel also vibrates more or less and may cause the split ring to rub on the core so as to abrade it to some extent. In prospecting coal beds it is therefore customary to use a double core barrel which contains a tube that slides down over the core as fast as cutting proceeds and protects it from wear.

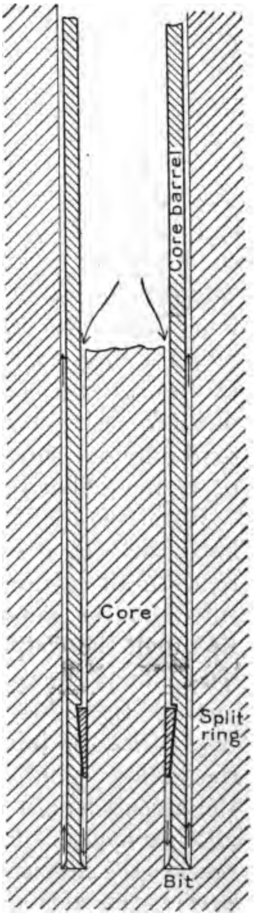


FIGURE 16.—Plain core barrel.

DRILLING OPERATIONS.

In starting a hole with a diamond drill the first requirement is to get down to rock. If the soil is thin, a pit is dug through it, a drive pipe is inserted, and a tight-fitting joint is made by chiseling out a seat in the rock, driving the pipe down and calking it firmly. If the soil covering is more than 10 or 12 feet deep, it is cheaper to drive the pipe to rock than to dig a pit for it. In places where the drive-pipe can not be set into the rock with sufficient firmness to keep out the surface water a hole is drilled inside the drivepipe with a chopping bit (fig. 15[5]) attached to the drill rods and a string of casing is put down to a depth sufficient to exclude the water.

When ready to begin drilling the drill spindle is set to the angle desired for the hole, a bit and core barrel are screwed to the lower end of a joint of drill rods, and other rods are added so as to bring the bit to the rock. The upper length of rod is then clamped in the spindle, so that the bit is a little above the rock, and the water swivel is screwed to the top of the rods and connected with the pump. The pump is then started, and when the return water begins to flow from the top of the casing the drill is started and the bit is slowly run down to rock. If the rock surface is not smooth, the bit will at first drill only one side, but soon all of the diamonds are cutting the rock, or, as the driller puts it, the drill has an "even bearing."

When the drill has been run into the rock the length of the core barrel drilling is stopped, but the pump is kept running long enough to wash all cuttings to the surface. A hoisting plug is then substituted for the water swivel and the line of rods is hoisted until the first drill-rod coupling is just above the safety clamp. (See fig. 15[6].) This clamp allows the rods to be hoisted, but grips them and guards against their loss by slipping downward and dropping into the hole. The top joint of rod is then unscrewed and passed out through the hollow spindle, the hoisting plug is lowered and screwed into the second length of the drill rods, and the line of rods is hoisted another length. Each joint in turn is removed until the core barrel reaches the surface, and the core is then taken out. By reversing the process the rods are again lowered into the hole, the water swivel is connected, and drilling is begun on the next "run."

CALYX DRILL.

DEVELOPMENT.

In 1873, shortly after Leschot first used diamonds for boring, large black diamonds of good quality could be purchased for $8 to $12 a carat; but since the introduction of the diamond drill they have advanced greatly in cost, and in 1910 were valued at $85 a carat for a two-carat stone or $50 for a one-carat stone. Borts are much cheaper; the rate in 1910 was about $18 a carat. As carbons weighing 1 to 4 carats apiece are used in diamond drilling, the price of a bit set up ready for drilling is a large part of the initial cost. For prospect work this cost has been somewhat reduced by decreasing the size of the bore hole, but for water wells the diameter can not be reduced to less than about 2 inches, and even this reduction in the size of the bit causes the drill rods to turn on so sharp a curve as notably to increase the difficulty of drilling and the probability of accident.

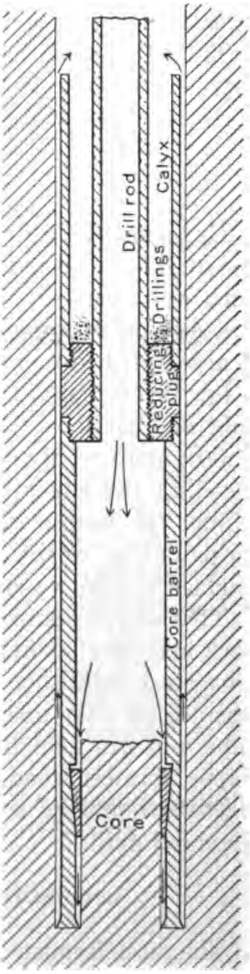


FIGURE 17.—Calyx core barrel.

On account of the increase in the cost of diamonds determined efforts have been made by engineers throughout the world to discover some method of coring rock without diamonds. Various hard substances, such as corundum, chrome iron, chopped steel, and garnet, and many varieties and forms of material have been tried unsuccessfully, attempt even being made to grind the rock by means of a free abrasive, such as steel filings, fed down the bore hole. Bits were also made of the hardest metals, and it was due to experiment along this line that the calyx drill was invented in Australia. It is now in use in many parts of the world.

DESCRIPTION.

The hoisting and driving machinery of the calyx drill is similar to that of the diamond drill, and feed water is supplied through a swivel and hollow drill rods. The bit of the calyx drill is made of hardened tool steel and consists of a toothed collar, somewhat like the cutting shoe of the hydraulic rotary outfit, but having longer barrel and teeth (see fig. 15[7]), the teeth being so set as to provide clearance to the core and to the bit and rods.

Above the core barrel a cylindrical chamber or calyx, open at the top, encircles the drill rods (fig. 17). Into it the coarser rock fragments torn off by the drill bit are caught as they are dropped by the upward water current when its velocity decreases. They are removed when the rods are hoisted to remove the core, and furnish a second record, in inverted order, of the materials penetrated. This record is of especial value in material too soft to yield a good core.

The action of the toothed bit in cutting the rock seems to depend largely on the torsional power of the drill rods, for the drill bites into the rock and resists turning until the twist of the rods forces it loose and partly around to a new grip. It thus has a " chatter " motion, which chips off fragments of the rock. Its action has been compared to that of the stone mason's chisel, which chips off rock fragments at each blow of the hammer.

The calyx drill is not restricted in size by such considerations of cost as is the diamond drill, and machines are built capable of taking cores 15 inches in diameter.

CHILLED SHOT METHOD.

Experiments in drilling by the use of loose abrasives poured down the drill hole led to the adoption for this purpose of chilled steel shot, such as is used in sawing marble and other stone. Other parts of the shot outfit are similar to those of the diamond drill, but cutting is accomplished by revolving an iron or steel tube on the shot. A slot a few inches long and half an inch wide cut into the lower end of the tube or bit allows the shot to reach the cutting surface more readily and be more evenly distributed. Distribution is also aided by slightly beveling the edges of the tube so that the shot may get under it. Under the weight of the drill rods the shot bites into the rock and chips out or wears off small pieces of it, which are brought to the surface by the water current.

That the supposedly round and smooth shot can thus wear away rock may seem at first almost impossible, but close examination of the tiny steel balls shows that they are slightly irregular in shape, and because of this unevenness of form they sink into the softer bit tube and are held firmly by it, abrading the rock surface as sandpaper abrades wood. The shot has no tendency to polish the hard rock—a tendency sometimes shown by the diamonds used in the diamond drill.

ACCIDENTS AND DIFFICULTIES IN CORE DRILLING.

The most frequent accident in rotary core drilling is the loss of rods through leakage. To recover them a screw tap may be employed, being lowered into the top of the rods, where it cuts its own thread, and thus obtains a firm grip. Taps (see fig. 15^8) are made in various sizes and are used to recover casing, pipe, and core barrels, as well as drill rods. If the rod of pipe is bent so that a tap can not be used at first, the upper portion may be cut away with a reamer until the tap can be inserted. The position and condition of broken parts may be ascertained, as in other drilling methods, by examining the lower end of the recovered portion, by using a mirror or by employing soap to obtain an impression of the upper part of the tools.

In using the diamond drill in formations containing hard pebbles or nodules loosely embedded in softer material the diamonds may be torn out and their recovery may be difficult. One device used to recover them is a ball of beeswax attached to the end of the rods.

Creviced rock offers difficulties to all core drills because of the uneven bearing it affords to the bit, and hence its tendency to deflect the hole. Crevices also cause loss of feed water and also of shot, when it is employed. These losses may perhaps be stopped by pouring into the hole oats, bran, sawdust, or other material that will swell under the action of water and fill the crevices. Care must be taken, however, that this material does not pack around the bit and prevent its withdrawal.

COMPARISON OF CORE-DRILLING METHODS.

The diamond drill is especially adapted to penetrate hard rock to great depths, and will bore a hole at any angle; hence it is especially useful in mineral-prospect work. It is somewhat restricted by the rock formation, however; for example, no diamond-drilling firm will send a drill into the lead and zinc districts near Joplin, Mo., for the limestone there contains many chert nodules, loosely embedded, which tear out the diamonds. In highly inclined and flinty rocks there is also danger of loss of the stones. The high cost of diamonds limits the use of this drill to boring holes of small diameter, and hence to the higher classes of work, such as prospecting for ore deposits.

The calyx drill is commonly used to bore much larger holes than the diamond drill, and in soft or moderately hard material it is cheaper. In very hard rock it works more slowly, however, and it is not adapted to boring holes at an angle greater than about 45° from the vertical. It is largely employed in coal prospecting and in boring holes for testing foundations.

The shot method may also be used in obtaining cores of large diameter. In very hard material it is more efficient than the calyx cutter, but it is not adapted to soft material. It may be used for boring holes at any angle, provided the drill is rotated rapidly and the shot kept properly distributed by centrifugal force.

All rotary core drills are portable and, as they can be taken apart for transportation on pack animals, can be used in regions where more cumbersome outfits are debarred. Nearly any power can be used—electricity, compressed air, steam, gasoline, horse, or hand—but where its use is possible steam is usually the best.

The three methods of rotary coring are sometimes used in boring the same hole, the style of cutting bit employed depending on the character of the material that is being penetrated. The shot and calyx bits are frequently interchanged, and on one of the leading makes of core drill the outfit is expressly designed to use a toothed cutter bit in soft and moderately hard rock and shot in penetrating the hardest materials. For this purpose a double water swivel is used, through one neck of which the shot is fed into the rods.

The percussion core drill (see p. 59) should prove valuable in sampling coal beds and in other work in comparatively soft formations in localities where a cable rig can be advantageously set up.

MINOR METHODS OF WELL SINKING.

BORING.

In alluvial deposits along streams and in other unconsolidated deposits of gravel, sand, and clay wells 2 or 3 inches in diameter are in some parts of the country bored to the ground-water level with a hand auger made by welding a carpenter's auger to a rod or pipe. The auger works more efficiently if the centering point is cut off and the lips are shaped as shown in Plate IV, 3. A wrench formed of a plumber's tee and two short pieces of pipe may be used to screw the auger into the earth and pull it out with its load of material, and the rod may be lengthened by adding other sections of pipe as sinking progresses. (Pl. IV, 1.)

Another much-used type of auger is formed by making a spiral coil of tire iron, shaping a cutting bit on its lower end, and welding or riveting the auger thus formed to a joint of rod or pipe. (Pl. IV, 2.) Where the depth to water is not more than 25 feet these small augers may be fastened to a section of pipe long enough to reach to water. As the auger is heavy when loaded with material, a windlass or a small derrick with pulley blocks may be used in lifting it, and a platform may also be built from which the auger can be steadied and turned. In boring through dry sand or other loose deposits a little water should be poured into the hole to cause the material to cling to the auger.

Small wells bored with augers are adapted mainly to localities where the water level stands above the suction limit, for the hole usually bored is not large enough to admit a pump cylinder. The best suction pumps will raise water to the surface from a depth of about 28 feet.

To complete these shallow wells, a pipe 1½ or 2 inches in diameter, with a suction or pitcher pump (fig. 18 ^{5}) screwed to its upper end, is inserted to a point a short distance below the water level. In

1. SMALL EARTH AUGER; 2, 3. EARTH-AUGER BITS; 4. DRIVE POINT AND SCREEN.

relatively coarse material a natural strainer is soon formed about the lower end of the pipe by pumping out the finer sand, and it is usual to drill a number of small holes along the lower part of the pipe to aid in admitting the water. In finer material a screen is used to prevent the well from becoming clogged.

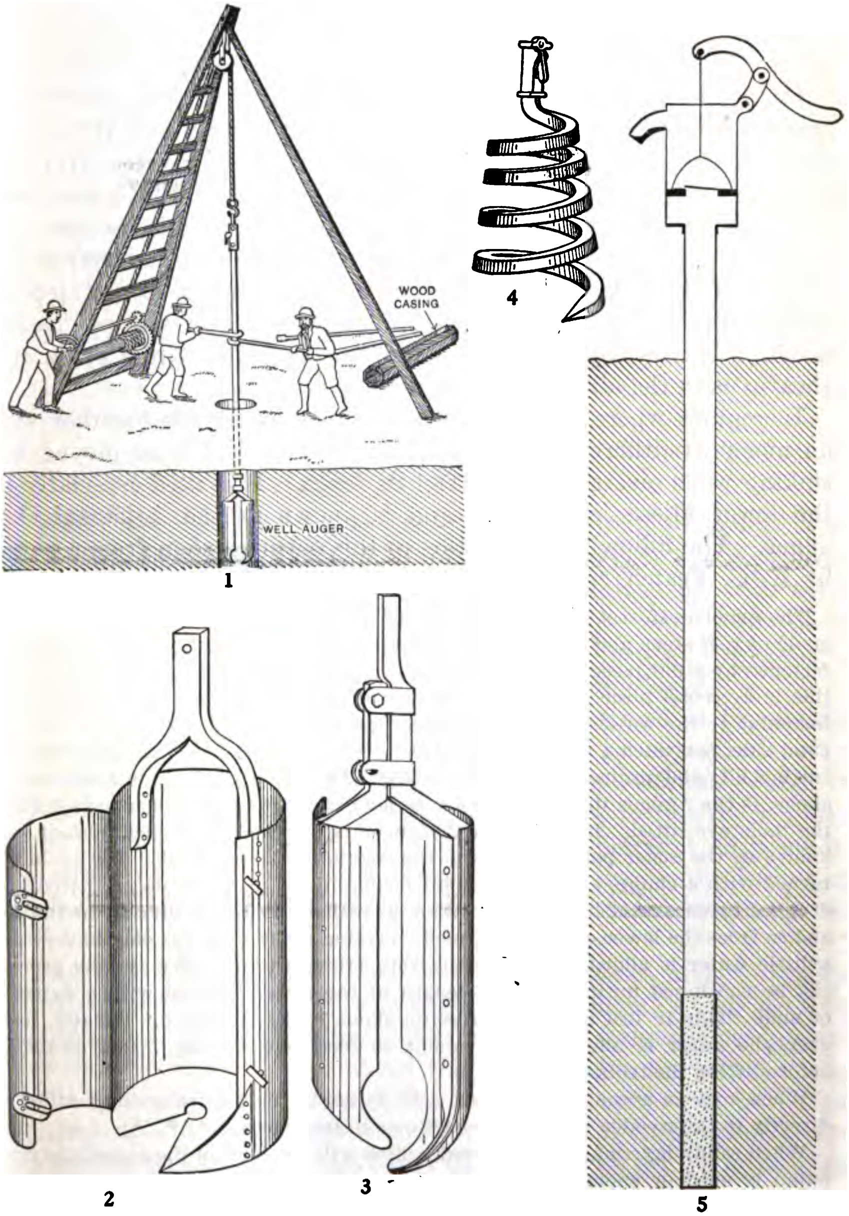


FIGURE 18.—Well-boring tools. 1, Ordinary well-boring outfit; 2, 3, well-boring augurs; 4, special auger for penetrating bowlders or rock; 5, suction pump.

For boring wells of larger diameter augers of other forms are used, and correspondingly heavier apparatus is employed for turning and raising them. Different shapes of auger are employed for penetrating different materials. Two common shapes are illustrated in figure 18^{2-3}. The larger augers range in diameter from 3 to 36 inches.

Casing is not usually required until the auger reaches saturated sands. Its use is then necessary to prevent caving and it may be driven down by a wooden maul or ram. Mud and water-saturated sand may be bailed out with a sand bucket, which in the smaller machines is handled with wooden rods instead of a cable, as the rods enable it to be more easily pushed down into the soft material at the bottom of the hole. Hard layers of material may be penetrated by substituting for the auger a drill similar to that used with percussion outfits. It may be operated by hand, in connection with a drum and sheave, as in the self-cleaning method.

In regions where the formation is clayey and holds together well an auger of different shape has been devised and is employed for sinking wells several hundred feet in depth. It is used especially in the lower Mississippi Valley and is known as the Arkansas clay auger. The following description of this outfit is taken from a paper by A. C. Veatch:[a]

> The auger is 15 feet long. It consists of an auger barrel 4 feet long, which is made of cast steel, and resembles a 3-inch pipe sawed vertically in half. This is fastened by a flat piece of iron to a second auger barrel, 1½ to 2 feet long; above this is a second piece of flat iron, square at the top and cut with threads for fastening to the wooden poles. At the bottom of the auger barrel, on the right-hand side, is riveted a steel-cutting edge. * * * This is commonly called the cutting bit, and projects inward 1¼ inches. On the opposite side and slightly above, is the "auger lip," which helps to hold the dirt in the auger barrel when the tools are lifted. In operation the auger is fastened to a short 10-foot pole known as the auger pole, and this to the regulation 26-foot pole. The tools are turned with a clamp, and when the bit begins to choke, the tools are lifted and dropped by means of a windlass. This operation jumps the dirt up in the bit, and so frees the lower end; it is termed "making a slip." If the clay is very dry a little water is added, and with the very sticky Cretaceous clay this process can be continued until the whole length of the auger is filled with a cylinder of mud. This 15 feet of mud represents about 10 feet in depth. Usually, however, the auger is filled for only about 10 feet, representing 7 feet of depth, before lifting the tools.
>
> When rock is encountered, a bar drill is used. This is sometimes attached directly to the wooden poles and sometimes to iron poles. * * *
>
> When sandy layers are encountered, which will not hold in the auger, the sand pump is used or enough clay is dumped in the hole to make the sand stick together.
>
> In cases where wells of larger diameter are desired, or where it is necessary to enlarge the upper part of the hole for wooden casing, the 3 or 3½ inch hole made with the Arkansas clay auger is enlarged with a reamer.

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[a] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas. Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 95, 97.

PUNCHING.

In a few localities where the material is very clayey wells are sunk by a punch instead of an auger. Of this method and its use in Arkansas and Louisiana Veatch says:[a]

> In regions where there are uniform clay beds without rocks or bowlders wells are often made with a well punch. This consists of a cylinder of steel or iron 1 to 2 feet long, split along one side and slightly spread. The lower portion is very slightly expanded, sharpened, and tempered into a cutting edge. In use it is attached to a rope or wooden poles and lifted and dropped in the hole by means of a rope given a few turns around a windlass or drum. By this process the material is forced up into the bit, slightly springs it, and so is held. When the bit is filled it is raised to the surface and emptied. When working in very dry clay water is sometimes added to aid the bit in "picking up" the material. Thin sand layers are passed by throwing clay into the well and mixing it with the sand until the bit will take it up.
>
> This process is not very extensively used in this region, and is not so practicable as the Arkansas clay auger.

DRIVING.

Where the water level is within the suction limit of about 25 to 30 feet below the surface and the water-bearing beds are unconsolidated, small water supplies may be cheaply obtained by wells sunk by driving into the ground a strainer and drive point fastened to a piece of pipe. Other lengths of pipe are added and driving is continued until the strainer reaches a water-bearing layer.

Unless the depth at which water can be obtained is previously known, the well is tested from time to time by a suction pump screwed to the upper end of the pipe. When desirable water is reached the well is pumped rapidly for some time to free the strainer from particles of sand and clay. The coarser material adjacent to the strainer is thus washed free of sand and forms a natural filter at the bottom of the well. One style of drive point and screen is shown in Plate IV, 4.

The pipe may be 1 inch to 3 inches in diameter, and is usually driven into the ground by a wooden or iron maul, which may be manipulated by hand. Often, however, a heavy weight is used, operated by a revolving drum and hoisting sheave, as in the self-cleaning method (p. 64), or by horsepower devices of various styles. The greatest difficulty encountered in driving wells is in striking rocks. Unless the rocks yield to the blows of the maul or can be broken up by explosives, the well must be abandoned.

Clay and sand often cling to the screen and render it worthless. To obviate this the pipe may be driven to the required depth with

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[a] Veatch, A. C., Geology and underground water resources of a portion of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 97.

only a drive point and then pulled up a distance equal to the length of the screen. The drive point, which fits loosely on the pipe, remains behind and the screen is lowered upon it. This style of screen can also be removed and cleaned if it becomes clogged and ineffective, but it can be successfully used only when the depth to the water-bearing layer is known, since a test for water can not be made until the pipe is raised.

A modification of this outfit consists of a screen attached to a drive point and so arranged that the drive pipe slips down over the screen and rests on the point while the two are being driven. In testing for water the pipe is withdrawn a foot or two, a pitcher pump is screwed to its upper end, and the well is tested by pumping. If water is not procured at the depth tested the pump is removed and the pipe is driven down again to the drive point and deeper into the ground. The only drawback to this method is that pebbles may lodge against the screen when the pipe is withdrawn, and when it is driven down again they may tear the screen and impair its usefulness.

If the water that is tapped contains a large amount of iron a thick crust may form on the pipe and screen and reduce the inflow of water, or even shut it off entirely. The incrustation may be loosened and broken up into fine particles that may be pumped out with the water by pulling the pipe a few inches, by driving it down a short distance, or even by rapping the pipe sharply.

The driven well is used to a large extent in the Atlantic and Gulf coastal plains, and is becoming common in the Mississippi Valley and the prairie plains. It is much used to obtain water supply for stock in farm pastures where the ground water is a short distance below the surface. It has also been used with great success in army camps in many parts of the world. British army officials call it the Abyssinian well, as it was first used extensively for army water supply during the Abyssinian campaign of 1895.

The driven well has the disadvantage of using surface seepage water which is likely to be contaminated. The site of the well should therefore be carefully selected and the safety of the water be determined from the character of the material penetrated, the direction of surface drainage, and the depth of the well.

SPECIAL OPERATIONS IN DRILLING WELLS.

The sinking and finishing of wells involves a number of special operations and is attended by many difficulties. The following discussion pertains especially to wells put down with standard outfits (see pp. 34–55), although most of it is also applicable to wells drilled by other methods.

PACKING.

Necessity.—In constructing a well to obtain flowing water it is essential under some conditions that a water-tight joint be made between the casing and the rock; otherwise water that enters the well below the joint will find an outlet, and on rising outside the casing will enter porous sands at a higher elevation and fail to reach the surface. Furthermore, if porous rock is penetrated below the point to which the well is cased, it may be necessary in order to conduct the flow to the top to insert a line of tubing to a point below all such material.

In oil wells a small amount of water may enter at the point where the casing joins the rock without doing serious damage if the head of the oil is strong and forces all invading water to the surface, for the water may be easily separated from the oil in the receiving tank by gravity. A gas well, on the other hand, should be dry, unless the gas pressure is so great that all water is held back by it. Moreover, gas always escapes under natural pressure, while oil is not uncommonly pumped, so that in oil wells the water is brought to the surface and does not accumulate as it would in gas wells.

It was thought essential at one time that water should be cased off during drilling operations, but the presence of water in some of the Pennsylvania oil fields, notably at Macksburg, led the drillers to experiment successfully with "wet" hole drilling, which saves the cost of the additional casing otherwise necessary. Casing is not now so extensively used until the well approaches the oil sands.

Near Chicago a bed of soft shale occurs at a depth of about 1,000 feet. This material is prevented from caving and clogging a well by placing a packer below it and allowing a piece of pipe to extend upward from the top of the packer to a point above the upper surface of the shale. Where water under pressure is encountered in the shale it is necessary to extend the pipe until it reaches beyond the height to which the water will rise. Drilling is then continued through the pipe and packer.

In the Kittanning fields in Pennsylvania several gas sands are encountered. The pressure in the upper sands has been reduced by years of flow from the wells until it is much less than in the lower gas-bearing layers. If the gas is allowed to come into the well under its own pressure, it forces its way upward until it reaches the upper sands into which it leaks. This process sometimes results in one well supplying gas to an adjacent one. The discovery of the rejuvenation of gas wells in upper gas-bearing sands by sinking new wells to lower sands in which gas was under greater pressure led to recognition of the necessity for separating the several productive layers. For this purpose a gas packer, similar to the one shown in figure 9[18]

(p. 53), is lowered into the well to a point above the lower and more productive gas sands, with casing extending from the packer to the surface. This arrangement separates the gas of the upper and lower beds so that both sources can be drawn upon. In this way the entire flow of gas from the deeper sands is confined to the well that taps them.

Packing methods.—In oil wells the water in the rock between the surface and the capping stratum overlying the oil sands is shut out by first drilling 10 or 12 feet into the compact shale that ordinarily forms the overlying stratum. After the hole has been cleaned out a few bucketfuls of moist drillings are thrown into it and the string of casing is then inserted and set in these drillings in the bottom of the hole. The driller then redrills the loose drillings with a smaller bit. That portion of the cuttings which is between the casing and the wall of the well settles down very compactly and becomes as effective as clay in preventing water of higher water-bearing strata from entering the drill hole. The effectiveness of this operation is increased by a process called "reaming out the hole," which in this connection signifies the substitution of a smaller bit than the one previously used and drilling with a shorter stroke. In this way the wall of the well is made smoother than it would otherwise be, and the hole is tapered to a size a little less than that of the drive pipe. Into this funnel-shaped hole the pipe is gently driven, making a snug joint.

Testing joints.—The joint may be tested in two ways. In one method the casing is filled with water and allowed to stand. If the water does not sink away the joint is known to be tight. The other method consists of lowering into the well below the joint a casing tester—a funnel-shaped instrument with an anchor attached that enables it to be set at any point in the well. It fits the well snugly and prevents water from passing it on the outside. After it has remained in the well for a few hours or days it is withdrawn and examined. If it contains no water it is evident that no leakage occurs, and drilling will then be continued.

If a joint continues to leak after the casing has been reset, the pipe may be withdrawn, closed at one end, connected with the boiler, and tested by steam. If no defects are found it is put back and set into the rock at a greater depth. If the rock at the bottom of the casing is broken and full of crevices, a tight joint can not be made at that point. This condition occurs infrequently, but when it does happen, if it is imperative that the joint be made water-tight, an enlarging drill or reamer (fig. 6^6, p. 40) is used to make the hole large enough to let the pipe down to a point where a tight joint can be made in the solid rock. This obviates redrawing the entire string of pipe.

Flaxseed.—In the early days of oil exploration in this country a bag of flaxseed was sometimes inserted at the point where the casing was to be set, the casing was let down, and that part of the bag which occupied the center hole was drilled out, leaving a considerable amount of seed between the casing and the well wall. This seed quickly swelled and closed the place in which it lay, thus preventing the entrance of water. Bags of beans and peas have also been used in a similar manner. For use a short distance above the end of the pipe the bag of flaxseed may be fastened around the casing, so as to swell and fill the space between the casing and wall of the well.

Cement.—Another method consists in filling up 5 or 6 feet of the bottom of the hole with cement, into which the casing is set. The cement hardens and excludes the water, and the portion within the casing is then drilled out. This method has been much used in the Baku oil fields of Russia, but its proper application is said to require great skill, as the settling qualities of cement are destroyed or seriously impaired by contact with oil or by the presence of large quantities of salt or other minerals in the water. Furthermore, the cement is expensive, and it deteriorates very rapidly if stored. Another unavoidable difficulty in its use inheres in the fact that there is usually water in the drill hole at the time that means are taken for its exclusion, thus making it necessary to convey the cement to the well bottom in tubes, and not allow it to filter through a long column of water. Flush-jointed, high-pressure tubes with extra long screw sockets are required for this work.

The process of cementing is carried on in Russia in a way very different from that followed in this country. The casing used is of unusually large size, ranging up to 36 inches in diameter. After being set it is entirely filled on the inside with a mixture of clay and sand, and cement is then carefully poured into the space between the casing and the rock. The cement excludes all water from this space and prevents its entrance into the well through imperfect joints or rivet holes, for the casing of Russian wells is not like that used in this country, but is thin, and the joints are riveted instead of being screwed together. After cementing has been completed the clay and sand on the inside of the casing are removed in the same manner as the original rock which occupied that space, but of course in a much shorter time, as the material has not had time to become compact.

Asphalt.—Asphalt has also been used for packing, being melted and poured down the outside of the casing so that when cool it forms a solid mass that water can not penetrate. The method is expensive, as the water in the well has to be heated with steam before the asphalt is poured in; otherwise the meeting of the two fluids congeals the asphalt and prevents it from flowing down where wanted. Trouble has also resulted from the refusal of the asphalt to set, even after considerable time, for, being viscous, it exerts a great external pressure on the casing and threatens to crush the latter if much is used.

This method of shutting out water has therefore not attained importance.

Rubber.—In many wells it is much more economical and effective to case off the water by rubber packers, which are made in styles to suit various conditions. The device in most common use (see fig. 9[13]) consists essentially of two metal cylinders united by a third hollow cylinder of rubber, usually an inch or two thick and varying in length and diameter with the special conditions to be met. This packer is lowered into the well by lengths of pipe to the position which it is to occupy. A weight is then dropped into it, which releases the wedges and spring, A (see fig. 9[13]); the spring throws the wedges up the taper of the cone, B, and when the packer is lowered under the weight of the drilling tools or casing the wedges catch the wall of the well. The rubber cylinder, C, expands outward and snugly fits all the irregularities of the well wall, thus preventing the passage of water. When once placed, this packer can be raised, but it can not be lowered again without being brought to the surface and reset.

In some wells where a small amount of oil or gas is struck in upper strata the attempt to obtain a greater production by drilling the hole deeper results in finding water instead of oil or gas. To shut off the water a packer consisting of a rubber plug with a tapering hole is used. A tapering mandrel, either of wood or iron, is driven into the plug and expands the rubber to fit the wall of the well so as to effectually shut off the water below.

Rubber packers are also employed in drilling wells where gas is encountered above oil-bearing strata. Instead of casing off the gas or allowing it to waste in the air a gas packer is introduced, which confines the gas between the casings and forces it to the surface.

After a packer has remained in a well for some time and has becomes embedded by the accumulation of sediment from the well wall it may be jarred loose and then removed by connecting it to a packer jar.

Concerning the durability of rubber packers it is difficult to make definite statements. It is, however, safe to say that the rubbers do not become useless from decay in a few years. The material used for packers contains probably not more than 60 per cent of pure gum. The greatest difficulty found in a packer made of high-grade rubber, and to a greater or less extent in any packer containing rubber, is its tendency to swell. This swelling does not affect the efficiency, but makes it very difficult to remove the packer if the casing is pulled for repairs or for cleaning. Packers are usually destroyed, not by rotting or by any chemical action while in the well, but by being torn during removal.

CLEANING.

In water-bearing or oil-bearing sand or rock that is firm and hard and will stand up in the well wall, a well may be completed simply by cleaning out the pores of the productive layers by strong pumping, which draws into the well the finer drillings that may have collected on the side of the hole and increases the delivery of water or oil. While cleaning is being done the pumps should not be stopped until sand is no longer discharged with the liquid, otherwise the sand will settle about the valves of the pump and make it impossible to start pumping again without drawing the pump rods and valves, cleaning them out, and resetting them.

An interesting operation in the care of oil and gas wells is the cleaning of the hole after the well has been producing for some time. Many of the first wells drilled in an oil or gas region penetrated only the first few feet of productive sand, the pressure being so strong at that depth that it lifted the tools from the well, or at least prevented further drilling. In time, however, such wells become clogged with sediment, the pressure decreases owing to the removal of gas and oil, and the wells must be cleaned to become profitable producers.

Where the sands carry gas or oil under light pressure, the hole is drilled through them and three or four feet into the underlying formation. A chamber is thus formed in which sediment may collect, leaving the whole surface of the sands available for the discharge of gas or oil. Some wells accumulate three or four feet of sediment in as many years. This settles and becomes as hard as the original rock.

In order to clean a well a derrick may be erected over it, as when it was first drilled. The other parts of the outfit used in drilling are then set up, the accumulated sediment is drilled loose and bucketed out, and the hole is deepened so that the advantage of the increasing pressure with depth may be obtained, or a reservoir supplied in which the collecting sediments may be caught. The derrick that one sees erected over oil wells in some oil districts is not usually the derrick used in drilling the well, but the one erected afterwards to clean the well or draw the pump rods, though in many districts the derrick used in drilling is retained. In cleaning out old wells whose rig timbers and wheels have rotted, resort is sometimes had to a mounted rig, which can be quickly run into position under the derrick.

At each cleaning a charge of 80 to 100 pounds of nitroglycerin is exploded in the bottom of the well to increase the yield. In many oil fields this is done regularly. Cleaning may become necessary again because of the caving in of the oil sand as the result of torpedoing, for in torpedoing the well even very hard rock is broken up and may cave into the hole. The cleaning of a well in this way often results in increasing the flow by 10 to 15 barrels a day. The operation as above described costs about $400. Some wells are cleaned every three or four years; other wells drilled twenty years ago have not been cleaned since they were put down.

The pores of an oil well may also be cleaned by a process called "flooding." This is to be distinguished from the term "flooding" as applied to the natural entrance of water into the oil and gas sands. In order to clean a well by this process, a large quantity of crude oil is poured into the well down one side of the casing. This runs down with great velocity, and as it passes over the well wall it cleans out the pores by friction and suction, and thus allows a greater production. The yield of wells treated in this way is never greatly increased, but the operation is very simple and inexpensive, and the increase is generally sufficient to make it profitable.

SCREENING.

If the well is sunk into unconsolidated materials, such as glacial material, coastal-plain deposits, river flood plains, and waste-filled valleys, a screen must be used which will permit water or oil but not sand in serious amount to enter.

In the northern part of the United States oil wells are not usually obtained in unconsolidated materials, but in California and in Texas they are not uncommonly sunk entirely in such deposits. In the Texas oil fields the screens or strainers are made of ordinary pipe, usually 2 to 6 inches in diameter, perforated with holes about one-quarter inch in diameter and 2 inches apart. The pipe is then wrapped around with iron wire. If the sand is fine, the wire is wrapped close; if it is coarse, space is left between successive wrappings. This kind of strainer is supplied by machine shops throughout the oil fields, and can be made by any mechanic.

A water-well screen similar to the one just described is in use in the Mississippi Valley from St. Louis to the Gulf, and is made by wrapping No. 14 wire, 10 to 14 wires to the inch, around perforated wood or iron piping. The closeness of the wrappings, as in the case of the oil-well screens, depends on the fineness of the material to be screened out. Wooden piping or tubing as a base for the screen is often preferred for water wells on account of the rusting of iron pipe. In some wells these screens are 100 feet long. The weight of the wire screen and the impact of the sand pressing against it when set prevent the buoyancy of the wood from lifting the pipe.

Patented strainers are also used, especially in water wells. Some makes, like the Layne strainer, shown in figure 19, *a*, differ from the shop-made ones in the shape of the wire used. In the Layne and similar streainers the wire presents a smooth surface to the sand, and thus reduces the clogging of the screen and insures greater production and a longer life to the well.

The Cook well screen (fig. 19, *b*) is also in favor with water-well drillers and is used extensively throughout the United States. It consists of a single piece of seamless brass tubing, perforated by horizontal slits, which are made in different widths for different sizes of material, and are cut with a beveled edge on the inside of the screen to give a minimum amount of friction in the slit with a maximum amount of water delivered, and a smooth outer surface that reduces the clogging of the apertures to a minimum. The screen may be set in the bottom of the well, the pipe drawn until it is almost flush with the top of the screen, and a lead seal inserted at the joint, or the screen and pipe may be united by a screw coupling.

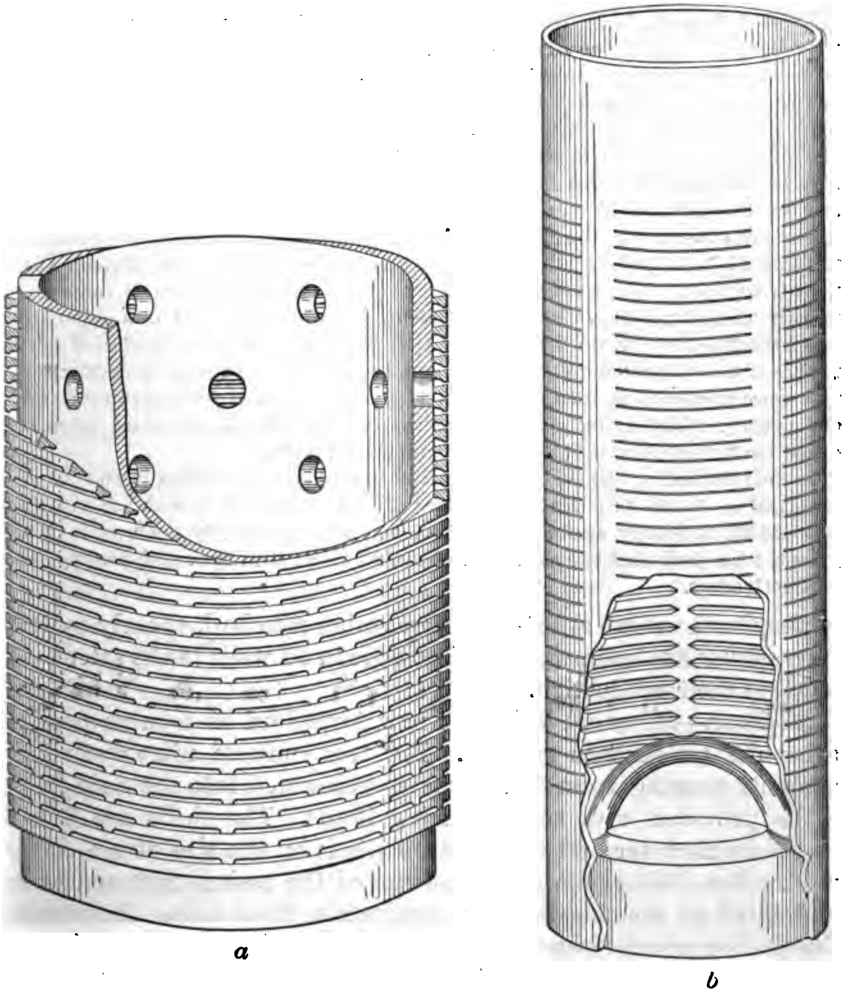

FIGURE 19.—Well strainers: *a*, Layne strainer; *b*, Cook strainer.

TORPEDOING.

OIL WELLS.

In an early record of the development of the Pennsylvania oil fields the following statements occur concerning the practice of torpedoing wells:[a]

> In 1862 Col. E. A. L. Roberts, then an officer in the volunteer service and with his regiment in the Army of the Potomac in front of Fredericksburg, conceived the idea of exploding torpedoes in oil wells for the purpose of increasing the production. He made drawings of his invention, and in November, 1864, made application for letters patent. In the fall of the same year he constructed six torpedoes, and on the 2d of January, 1865, he visited Titusville to make his first experiment. Colonel Roberts's theory was received with general disfavor, and no one desired to test its practicability at the risk, it was supposed, of damaging a well. On the 21st of January, however, Colonel Roberts persuaded Captain Mills to permit him to operate on the Ladies' Well, on Watson Flats, near Titusville. Two torpedoes were exploded in this well, when it commenced to flow oil and paraffin. Great excitement, of course, followed this experiment and brought the torpedo into general notice. The result was published in the papers of the oil region and five or six applications for patenting the same invention were immediately filed at Washington. Several suits for interference were commenced, which lasted over two years, and decisions in all cases were rendered declaring Colonel Roberts the original inventor.
>
> Nothwithstanding the success of the first experiment, operators were still very skeptical as to the practical advantages of torpedoes, and it was not until the fall of 1865 that they would permit the inventor to operate in their wells to any extent, from fear that the explosion would fill them with rock and destroy their productiveness.

Despite the above assertions several other men had, as early as 1860, successfully exploded charges of powder in oil wells in the attempt to increase their production.

Methods.—Many oil wells are now torpedoed as soon as possible after the oil sand is reached. For this purpose nitroglycerin in amounts ranging from 3 to 8 quarts is lowered into the well in tin shells provided with suitable firing heads. The shells are 3 to 5 inches in diameter and the length depends on the size of the charge used. The shell is placed in the top of the casing, fastened there, and filled by pouring in the nitroglycerin from cans. A lowering line is then attached and the charge is slowly lowered to the bottom of the well, when the hook at the top of the can disengages and the line is hauled up. For a large shot several shells are used, one resting on top of the other. If it is desired to shoot the well some distance from the bottom, an anchor is used. This is simply a small tube, which supports the shell at the proper depth. The nitroglycerin is then exploded by dropping into the well a small iron casing called a "go-devil," which strikes the can and explodes the charge. Another method of exploding is by means of the time fuse. The squib which

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[a] Henry, J. T., The early and late history of petroleum, 1873, pp. 251–252.

carries the time fuse is made hollow in the center to hold about a pint of nitroglycerin, and into this nitroglycerin the end of a long fuse is inserted, on which is a large fulminate cap. The fuse is cut so as to burn a few minutes, according to the depth of the well. It is inclosed in a hollow covering, the interstices are filled with sand, and after lighting it, it is lowered on top of the charge.

Torpedoing, of course, is practiced only in wells whose production is slight when they are first drilled or becomes so after they have yielded oil for some time. A well may be finished for the torpedo by an enlarging reamer, which gives a chambered hole, and results in the charge producing greater effect. It is especially adapted to soft rocks where the crevicing of the oil sands can not otherwise be readily accomplished at a sufficient distance from the charge.

Effects.—In most wells the explosion takes place at so great a depth that there is little immediate surface effect, only a slight jar of the ground and a dull report being perceptible. In a few seconds, however, the enormous force of the explosion is shown by the violent ejection of oil, stones, water, and fragments of the tin shells.

The effects of shooting are not permanent, and after being shot many wells decrease permanently in yield. In some wells the flow may be again increased by lowering the tools and stirring the bottom—"agitating the well," as it is called. It is believed that when the tools are withdrawn a partial vacuum is suddenly created and the pores of the oil sand are cleaned by the heavier inflow of oil into the cavity formed by the explosion of nitroglycerin.

A good flow does not always follow a shot. Sometimes the shattered fragments, instead of being thrown out, become wedged together and choke up the hole. In this event the drilling tools must be put in again and the material drilled out. This is a disagreeable job, as the well is full of foul oil and the poisonous burnt products of nitroglycerin, which are occasionally thrown out over the men and the machinery.

When torpedoes are exploded in sands that are very friable large quantities of material fall into the hole and must be cleaned out. This is true of wells at Bartlesville, Okla., Casey, Ill., and Chanute, Kans. Agitation is also necessary in the friable sands, as so much material is finely pulverized by the explosion and driven into the pores of the sand that they are practically closed and oil does not begin to flow until they are opened again. That this action takes place is known from the stronger flow before than immediately after shooting and the flow after agitation of a very liquid mud, which is followed by a rapid increase in the flow of oil. The good effects of an explosion would therefore not be realized in friable materials if agitation were not practiced.

The explosion of a torpedo has a damaging effect on the casing if this extends down near the point where the discharge takes place, for it is bent and torn irregularly and is thus rendered more difficult to pull, should it be desired to save it later.

WATER WELLS.

Explosives are used to some extent in water wells for the purpose of increasing the supply and providing a reservoir for the water, and there appears to be no reason why, under favorable conditions, their use should not be as beneficial as in oil wells. If water is drawn from rock fissuring the rock will certainly increase the area from which delivery is made to the pump. In a limestone region, where the underground water, like the surface water, runs in more or less definite channels instead of percolating slowly as a broad and thick sheet, the torpedoing of a well would almost surely increase the number of contributory veins. In such a region the success of a well depends so largely on chance, the diameter of the hole being small and the water veins few, that torpedoing would seem to be beneficial to all wells and to determine absolutely the success of some. The experiment should be more generally tried.

FEATURES OF WELL CONSTRUCTION.

DIFFICULTIES ENCOUNTERED IN SINKING WELLS.

Accidents in well drilling are common and some of them may be unavoidable. Excessive strain on any part of the apparatus may cause it to break, and before drilling can proceed the broken parts must be removed and replaced. Many accidents are of trifling importance and cause little trouble or delay; others are very serious and may cause delays of weeks or months.

All the accidents that may happen can not be described here; only the more important ones will be noted. The common accidents may be divided into two classes—(1) those caused by losing tools in the well and (2) those due to geologic conditions. The contractor usually holds the driller responsible for accidents of the first class, but not for those of the second class, unless the formation is well known from previous borings.

LOSS OF TOOLS.

CAUSES.

Tools are usually lost as the result of one or more of the following conditions or causes:

1. A worn cable. The stretching and bending of the part of the cable immediately above the socket cause it to become thin and frayed after a few weeks' wear.

2. The imperfect attachment of the cable to the socket. The joint should be tested by putting a strain on the rope while the drilling tools are anchored at the surface.

3. Neglect in setting up the tools after each run. If the parts are not securely fastened together they become unscrewed and fall into the drill hole.

4. Paying out too much or too little cable. If too much cable is paid out, the jars will batter and break; if too little, the whole weight of the tools will fall on the cable and strain it excessively.

5. Crystallization of the iron of the tools through successive jarrings, brought about by the magnetization of the iron. The effect of magnetization on the drilling tools is to decrease their tensile strength. The screw pin of the auger stem may break from this cause.

Probably no other engineering operation requires more deftness and ingenuity than "fishing" in a drill hole, owing to the great depth of many drill holes and the small space in which the driller must work. To ascertain the nature of an accident one-half mile below the surface, in a hole perhaps only 6 inches in diameter, by means of a cable having a very appreciable stretch, is clearly an operation requiring great skill. As the string of tools is usually more than 50 feet long, weighs over a ton, nearly fills the hole, and is wedged in so tight that the strongest cable could not pull it loose in a straight pull, the conditions involved in some fishing jobs is obviously unusual. Occasionally the driller is compelled to break up the broken tool in the well, crushing it with the drill by repeated blows.

LOCATING LOST TOOLS.

The first step in recovering a lost tool is to learn the shape of its upper end and the position in which it lies in the well. This knowledge may be obtained by lowering over the tool a sheet-iron vessel containing soap or other soft material, in which an impression is easily made. An examination of the mold then enables one to determine the position of the tool and to devise means for its recovery.

If the fallen object has been caught in the well wall above the oil or water or lies in a dry hole, its position may be determined by reflecting light into the well from a mirror. It was perhaps this operation which suggested the invention of a photographic device for determinations of this character. The device has not been used much in this country, although it seems that where a considerable amount of money depends on the early completion of a well whose drilling has been delayed by loss of tools it could be used to great advantage. The device was invented by Mr. Loran, a Baku engineer, and both the instrument and process of photographing have been described by A. Beeby Thompson.

The device consists of a stereoscopic photographic apparatus, which is lowered to a point near the lost tool, light for the negative being furnished by an electric current carried by wires arranged in the camera. Concerning its construction Mr. Thompson says:[a]

> An internally blackened, bell-mouthed vessel, at the small upper end of which is fixed the stereoscopic camera, and at the sides of which are fixed two small electric lamps with shades reflecting the light downward, is attached to a sinker rod with guides. Incased in an air-tight chamber above the photographic device is an electric accumulator, which supplies the light, and interposed in the circuit is a small clock that can be regulated to produce contact at any desired time, switching on the light and opening the camera shutter at the same moment. Above this is placed a cylinder in which compressed air is stored, leading by minute tubes to the bell-mouthed photographic vessel beneath. By a clever device a quick upward or downward motion of a few inches causes a disk, nearly equal in size to the well, working freely on the central spindle, to rise or fall and transmit a motion to a lever which actuates an air valve leading from the air vessel. The pressure of air must exceed the pressure due to the submergence of the apparatus in the liquid, and on the air valve being opened the fluid is displaced in the bell-mouthed vessel and an undisturbed view of the lost article is secured. After an exposure of one or two hours the air is shut off by a repetition of the before-mentioned jerk and the apparatus raised.

Some very good photographs made in this way are given in Mr. Thompson's book, showing the exact shape and position of fallen cable, wrenches, and other tools.

It is strongly urged that drillers in this country try the invention where it is very desirable that the exact position of the tools be determined before fishing operations are begun.

RECOVERING LOST TOOLS.

Most of the instruments made for recovering lost tools are expensive, and so many of them have been devised that one contractor can not afford to own a complete set. Usually he purchases first the ones he is most likely to need and others as he may require them.

Slip socket.—If the drill is lost in the well, but is not jammed tight, it may be possible to lower a spudding spear (fig. 20^1) into the well and prod the top of the drill loose from the wall. The drill may then be grasped and removed by a slip socket (fig. 20^2), which consists of a pair of slips inserted in a tubelike instrument and suspended by a light string. The teeth of the slips are beveled upward, so that when the socket is lowered the slips readily move downward over the upper part of the lost tool. By quickly jerking the socket upward the string supporting the slips is broken, the teeth bite into the tool, and as the socket is raised the beveled groove in which the slips work narrows the space and causes the grip to become more firm. In this operation it is essential that jars be used to cause the teeth of the slips to bite as deep as possible into the drill, and also to jar the drill from the

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[a] Thompson, A. Beeby, The oil fields of Russia, 1904, 2d ed., 1908, p. 164.

rock in which it is held. If it is impossible to lift the tool, the socket may be driven down again. The slips are thus raised and are automatically caught on the side of the socket. If a harder pull on the object is required the socket should be brought to the surface and reset. If the jars should be broken and the string of tools fall into the well the tools may be withdrawn by lowering a slip socket of special pattern over the sides of the broken jar.

The slip socket was invented in this country and has been adapted to many uses and is more employed than any other instrument for lost tools. If it is properly arranged before being lowered into the well, it will not fail to seize the lost object and it grips it with greater and greater force as stronger pull is applied to the drill rope, and if the driller is unable to bring enough force to bear on the cable to withdraw the tools, it may easily be released and raised.

If tools have fallen far, and have become firmly embedded in the rock at the bottom of the well the fishing jars must be very long and the longest possible stroke must be given to the walking beam. The tools may usually be loosened by repeated blows and then removed.

Horn sockets.—If the tools have fallen only a short distance they may be removed by a horn socket (fig. 20^3), a tube with two slits, cut on opposite sides, which when jammed down over the fallen tools expands slightly and obtains a friction grip. It is cheap, easy to operate, and is almost as much used as the slip socket.

Electro-magnet.—Another device used in fishing is a powerful electro-magnet, by which a lost tool may be drawn out of a niche in the drill hole and recovered. The electro-magnet has been used successfully by Mr. Phillips, of the firm of Phillips & Worthington, New York City, in drilling a well in New Jersey, but the rigging up of the apparatus is expensive and difficult.

Rope spear.—If the cable has broken near its connection with the temper screw and has fallen into the well it may perhaps be withdrawn by catching it with a rope spear (fig. 20^4), a rod armed with upward pointing barbs, which is lowered into the well by a rope. If the drill is wedged in so tight that the cable can not be withdrawn by the spear a rope knife (fig. 20^5) is lowered, by which the cable is cut off as near as possible to the drill. The drill may then be withdrawn by a slip socket and the cable speared and removed.

Defective casing.—Two instruments that are frequently used in dealing with defective casing are illustrated in figure 20^{6-7}. If the casing has been dropped to the bottom of the well from a considerable height, it may be bent, or even twisted like a corkscrew, so that it can be withdrawn only in short sections. To do this the casing cutter (fig. 20^6) is inserted, the knives of which expand as the pipe on which it is screwed is rotated, and the casing is cut at any desired point. If the casing is only slightly bent it may be straightened by the use of a pipe swedge (fig. 20^7), dropped into it repeatedly in the manner in which the drill is operated from the walking beam.

REDRILLING AND ENLARGING.

If the methods just described are ineffective in removing the broken parts, the driller may shift the drilling tools a few inches to one side and redrill and enlarge the hole. By drilling some distance below the level of the top of the lost tools and spearing them out into the new hole, part of them may usually be grasped by a slip socket and withdrawn. If the drilling is done in relatively soft material the tools may be pushed to one side and passed by, thus drilling a second hole. This at first seems to be an almost impossible operation, but it is easily done, and is effective in disposing of even large broken instruments.

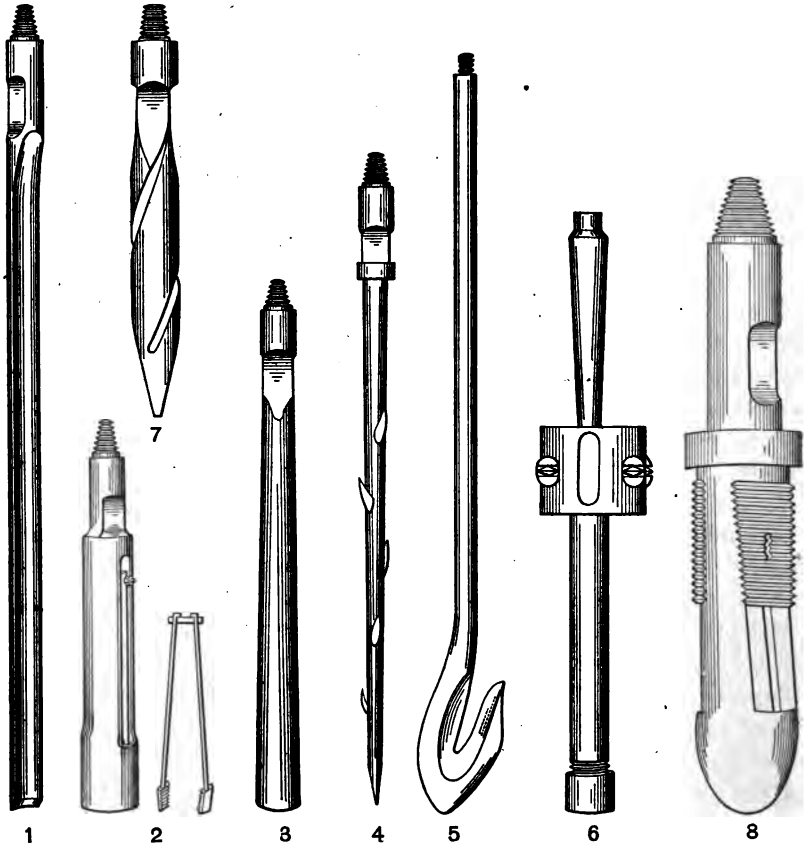

FIGURE 20.—Fishing tools used with standard drilling outfit. 1, Spudding spear; 2, slip socket for tools; 3, horn socket; 4, rope spear; 5, rope knife; 6, casing cutter; 7, pipe swedge; 8, slip socket for inside of pipe.

GEOLOGIC DIFFICULTIES.

SPALLS.

Spalls of rock or loose stones may fall from the wall of the hole on top of the drill and wedge it in so tightly that it can not be withdrawn by cable pull alone. This is a common accident in wells in highly creviced or fissured rock or in glacial till, without casing or drive pipe. The spalls or loose stones may usually be broken up by a smaller drill, and the tools can then be withdrawn.

In brittle sandstone and in shale the top of the string of tools may become jammed in a cavity in the wall of the well, made by the detachment of rock fragments. It is then necessary to bring the string of tools into their normal position in the drill hole by means of the spudding spear. They can seldom be loosened simply by playing on the cable.

BOWLDERS.

An incident that shows the close dependence of drilling on geologic conditions is the mistaking of a bowlder for bed rock. Ordinarily the driller determines whether the hard rock which the drill has struck is or is not a bowlder by noticing whether it seems loose and rebounds under the stroke of the drill. If it does not seem to be solid rock he endeavors to break it to pieces and remove it.

The bowlder may be so large that the driller mistakes it for bed rock, and after drilling into it for 3 or 4 feet sets the casing in the bowlder, substitutes a smaller drill, and proceeds as if he were in bed rock, but after drilling a few feet farther he again encounters sand or clay of the same character as that above the bowlder. He must then draw the casing set in the bowlder and ream out the hole to a size which will enable him to sink the proper casing through it.

The error of mistaking a bowlder for bed rock may be avoided by observing the drillings brought up to the surface and noting whether they are of material like the bed rock in the vicinity. In northern Indiana, for example, a driller may be pretty certain that if the drillings indicate granite, or schist, or trap, the drill is in a bowlder and not in the bed rock, which in that region is for the most part limestone. If the rock appears to be a bowlder, he will of course expect to find soft material below it and will proceed accordingly.

In the glaciated regions of North America the bed rock is overlain by a bed of till that ranges in thickness from a few feet to several hundred feet and contains many large bowlders. The bed rock in most places is shale, sandstone, or limestone, but the bowlders, having chiefly come from the north where the rocks are of different character, are chiefly of granite, schist, and other crystalline rocks; some bowlders, however, as those derived from the country rock, are of limestone and sandstone.

If a bowlder is especially hard, it may be blown to pieces by dynamite or rock powder tamped with a bushel or two of dry sand or clay. This may split the bowlder so that the casing will pass down between the broken parts, or it may break it into pieces so small that they can be further reduced by the drill and removed by the bailer. If the bowlder is to be broken by explosion, the casing should be drawn 3 or 4 feet above the charge, so that it will not be injured.

RUNNING MUDS AND CLAYS.

Mud produced from some shales hardens quickly when exposed to the air. If such mud runs into a well and fills the space between the drill and the well wall, it may solidify and interfere with the withdrawal of the drilling tools. A hole drilled through a stratum of such shale must be cased down and drilling must be pushed forward so rapidly that the mud will not have time to solidify. The drill may be freed from obstruction by this mud and withdrawn by slowly working it up and down so as to gain on the upstrokes, and the mud may be removed by small buckets or augers. If this method fails, 1½ or 2 inch pipes may be lowered into the well and the hardened mud and sand may be flushed out by a powerful water jet. Such a layer of mud and clay can sometimes be passed by casing it off with a short length of pipe and using a smaller drill, but the driller usually prefers to work patiently past it rather than to reduce the size of the hole by casing it off.

Even if only a small quantity of water is present, clay will "crawl" and relieve pressure by squeezing through very small openings in threads or sheets. The slow but forcible movement of plastic clay into a drill hole may fill the hole during a single night when drilling is suspended. When drilling is resumed the next morning the drill will strike this soft plug of clay and ram it down until the compression of the air below prevents its further movement. The drill may continue to pound on this elastic cushion for days, or even weeks, without making further progress while the clay slowly accumulates in the hole. The difficulty may be overcome by casing off the clay before it forms a plug or by jetting through the plug. Plastic clays are encountered in South Dakota and in the Atlantic coastal plain, but most of the glacial clays are so sandy that they yield readily to the drill even if the well does become clogged.

QUICKSAND.

Character of the material.—In drilling water wells in the soft coastal-plain formations that stretch from Cape Cod westward and southward along the border of the continent the most serious difficulty encountered is caused by beds of quicksand, which are as a rule interstratified with beds of coarser sand and of clay. The quicksand comes into the drill hole and must be bailed out in large quantities before the casing can be driven farther down and drilling continued. Under ordinary conditions quicksand will not yield its contained water, and therefore if it has a tendency to rise in the pipe the difficulty can seldom be obviated by pumping alone. The whole mass is saturated, its water can not be separately withdrawn, and it exerts practically hydrostatic pressure.

A driller in the Northern States may find pockets or lenses of clay or coarse sand in a quicksand layer, and these cause him to think he has passed through the quicksand. Coarse sand, such as "bar" sand, will not rise if the velocity of the water through it is less than about 2½ feet per minute. The drive pipe shuts off the water and quicksand above such a pocket of coarse sand or clay, but as soon as the drill penetrates the pocket the quicksand flows in and may rise to the height of the top of the deposit. If the bed is 20 feet or more thick, the pipe can not be driven through it on account of the resistance of the compact sand; and if the water in it is under great head, so as to force the sand up to or above the point at which the bed was struck, further progress may be almost impossible. In some wells quicksand has risen in the pipe 100 feet above the depth at which it was struck.

Pressure of material.—If the drill hole is not kept full of water, the pressure exerted by quicksand on well casing may be very great. Experiments have shown that quicksand saturated with water exerts a lateral pressure equal to one-half its vertical pressure. Beyond the point of saturation the pressure is hydrostatic, the vertical and horizontal pressures being equal. Quicksand can be confined only by using water-tight casing, for it is commonly so fine that it will pass a standard 100-mesh sieve. Saturated material of this fineness will flow wherever water flows. The lateral pressure of quicksand is exceeded only by that of clay, and the clay moves much more slowly.

Withdrawing tools.—When quicksand is encountered not only does the material require laborious excavation, but unless the drill is withdrawn rapidly it gets jammed in the hole and is buried by the sand. The driller is then under the necessity not only of cleaning out the hole, but also of recovering the drill before he can resume drilling. In this event it is usual to bail out the quicksand to the point at which the drill is stuck and then introduce into the well a wash pipe an inch or two in diameter. With this the quicksand is agitated (or jetted) and washed down to the surface. This operation continues until the drill is partly free, when a slip socket is inserted over its upper end and, with the assistance of the fishing jars, it is jerked free from the quicksand.

In connection with the up-and-down motion given to the drill while it is being removed from the quicksand, it must be raised with each stroke, and in this way gradually freed. The same method of procedure is required where quicksand comes into a well suddenly, the drill being moved up and down as if it were cutting into rock, while at the same time it is lightly raised at each upstroke. This operation must be carried on rapidly, otherwise the sand will pack about the drill and prevent its removal.

If the driller is working in sand of rather fine texture, he draws the drill at night, as otherwise the sand may creep up around the drill and "set" almost as hard as rock. The drill is seldom left in the well overnight on account of the danger from sand or of malicious cutting of the rope, or, in a rock well, of having a bowlder fall and become jammed between the drill and the well wall.

Penetration of quicksand.—If the layer of quicksand is only a few feet thick it may be penetrated by bailing out and then driving the casing. The pipe is driven as far as possible into the bed without bailing, and the quicksand may occasionally be passed through at one drive.

A thin bed of quicksand that lies near the surface may be shut off by driving sheet piling around the mouth of the well.

Difficulty caused by quicksand may be partly overcome by filling the bottom of the well with mortar or Portland cement, which sinks down through the quicksand and sets. The hole may then be drilled through the cement, which forms a wall that prevents the further inflow of quicksand. Stones, clay, and asphalt have also been dropped or poured into the hole to restrain the quicksand, with some success.

Water pressure.—The head of the water in quicksand is nearly always less than the elevation of the well mouth. Some drillers maintain that quicksand can always be penetrated by keeping the drill hole full of water. If the quicksand lies at a depth of several hundred feet and its head is 100 or 150 feet below the surface, a column of water in the well will exert a back pressure on the quicksand of 43.4 pounds per square inch for every 100 feet of drill hole, which will prevent it from rising in the pipe. The sand bailer may then be inserted and the well may be bailed through the column of water.

It sometimes happens that after bailing out large quantities of quicksand the pipe becomes bent, a fact that is explained by assuming that the quicksand bailed out is removed from beneath a higher layer of firmer material, such as till or clay, on only one side of the pipe, and that the pressure of this material against one side of the lower end of the pipe causes it to be thrown out of alignment. The remedy consists in keeping the hole full of water. This prevents the formation of such an artificial cave; or if the pipe has already become crooked, corrects the trouble by causing the pressure on the pipe to be equal on all sides.

If such a cave is formed beneath a layer of till, bowlders may fall down from its walls and become jammed against the pipe and prevent it from being driven ahead. The side pressure caused in this way may likewise be at least partly overcome by keeping the hole full of water. If the trouble is not remedied by this means, the process may be supplemented by drawing the pipe until the drive shoe is above the bowlder. The bowlder may then be crushed with the drill and the pipe driven ahead.

Pumping.—By keeping the shaft full of water, J. E. Bacon, in sinking a large open well at Charlotte, Mich., in 1904, removed quicksand by a powerful sand centrifugal pump. This method was also successfully employed at Millville, N. J., in sinking a well 8 feet in diameter to a depth of 36 feet, the lower 16 feet being through fine, saturated sand.[a]

Freezing.—Quicksand has been penetrated by shafts by means of freezing. This method was first employed in 1883 by F. H. Poetsch, a German mining engineer, who by using it sunk a shaft in a mine near Schneidlingen, Prussia, through a bed of quicksand about 18 feet thick, lying about 100 feet below the surface. As other methods had proved unsuccessful, Poetsch drove pipes into the quicksand and circulated through them a refrigerating brine which froze a wall of quicksand 5 feet thick around the proposed shaft. Excavation was continued within this wall, and the shaft was carried downward through and below the quicksand. The same engineer later excavated through 107 feet of quicksand by the same means. The process has also been used in this country in sinking a number of shafts, one of which is described by D. E. Moran.[b] The machinery used in freezing the quicksand consisted of the following essential parts:

1. An ammonia compressor or pump with suitable motive power.
2. Pipe coils surrounded by constantly changing cooling water. In these coils the compressed and heated gas coming from the ammonia compressor is cooled to such a temperature that, at the pressure existing in the coils, it condenses to the liquid form.
3. A valve, regulating the flow of the liquid ammonia from the above-described coils into—
4. A second set of pipe coils, surrounded by brine or other vehicle. The liquefied ammonia passes from the regulating valve into these coils and immediately expands, absorbing the necessary heat from the surrounding brine. From the coils the gas is led back to the compressor, completing the cycle.

The brine used was a 60 per cent solution of the impure calcium chloride of commerce. The cold brine was pumped from the refrig-

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[a] Ledoux, J. W., Eng. News, Mar. 12, 1903, p. 237.

[b] Moran, D. E., The freezing process as applied at Iron Mountain, Mich., in sinking a shaft through quicksand: School of Mines Quart., vol. 2, 1890, pp. 237–254.

erating tank through a system of distributing pipes and regulating valves to the ground pipes, and after circulating through these it returned to the refrigerating tank, the velocity of the brine in the downward flow pipes being about 2 feet a second. No protection was given to the connecting pipes above ground, so that these were soon covered over with a snow-like ice, the result of condensation from the atmosphere, and this served as a cheap and effective lagging.

Soon after the brine was started in circulation the ground began to freeze around each pipe, forming frozen cylinders, which increased in diameter until at the end of six days adjacent cylinders intersected and made a circular wall extending from the surface to the bottom of the drive pipe and thus formed a cofferdam inclosing the proposed shaft. Excavation was then begun inside this cofferdam, and no water came through the frozen wall at any time. The rate of freezing differed in different parts in the deposit, depending on the amount of water the parts contained. The smaller the amount of water the longer it required to effect freezing.

Some of the physical qualities of the frozen quicksand were noted.

> Frozen quicksand may be regarded as a mortar in which the cementing material is ice, and, as in a cement mortar, the strength will probably be found to depend on the quality of the sand and the presence of sufficient cementing material, as well as on the strength of the cement.
>
> Frozen quicksand looks like a fine-grained sandstone. It is perfectly homogeneous, breaks with a tendency to conchoidal fracture, and is as hard to work as a stone of similar character. When mixed with gravel or bowlders the mass resembles conglomerate or a concrete made with similar stone. The difficulty of working the material is more than doubled by the presence of gravel, which greatly increases its density and dulls the pick points or "moils" of the miners. The strength with which the quicksand adheres to the stone is shown by the line of fracture in such material. There seems to be no tendency for the rounded bowlders to pull out of the quicksand, but rather for the break to follow the shortest line, whether through flint or quicksand.[a]

Quicksand beds that lie near the surface can be thus frozen without very great expense, but the expense of freezing beds that lie at depths of over 100 feet will probably be great and the process will be slow.

FLOODING OF OIL WELLS.

DEFINITION.

Irremediable injury is constantly being wrought in both old and new oil fields by "flooding"—the invasion of the oil or gas bearing stratum by water from some higher source.[b] As water is heavier than either oil or gas, it displaces these substances or becomes mixed

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[a] Op. cit., pp. 248–249.

[b] The term "flooding" is also used locally in another sense with reference to cleaning wells (see p. 98).

with them, and not only damages the well into which the water first enters, but also floods the contiguous sands and may result in the destruction of an oil district.

CAUSES.

Some oil men contend that the admission of water to beds of productive sands will affect the production of a well by raising the oil or gas above the level of the bottom of the casing, but the whole surface of the productive sands on the well wall is left exposed, and any rise of oil or gas in the sands themselves would not affect their relation to the well.

In some wells flooding produces a mixture or emulsion of oil and water, which in the rock can only very slowly separate again under the influence of gravity.

Oil usually rests on salt water, and in order to keep the well in good condition as long as possible the oil should be pumped off the water slowly. In a state of rest the oil and the water are separated by gravity. The flow of oil from a well producing 500 barrels a day is so slow that it does not disturb the water, but if the amount is as great as 5,000 barrels a day the oil is drawn over the water so rapidly that the two are to some extent churned into an emulsion, and this effect probably extends some distance into the porous beds containing the oil.

An emulsion is also formed if the well has been put down too far into the oil-bearing strata and the water level has risen by reason of continued and rapid outflow of oil. Forced production is often practiced, however, because it enables the owner of one well to draw oil from under his neighbor's property before his neighbor has had time to sink a well. In small fields this forced production is important, because the oil is soon exhausted, and each well owner tries to get as large a share of the supply as possible.

Rapid pumping may exhaust a well and cause water to rise in the area around its lower end so as to flood adjacent wells and render them useless, as was shown in the fields at Chanute, Kans., at Humble, Tex., and some fields in Illinois.

Rapid pumping may have the further disadvantage of making it necessary to store large quantities of oil at the surface, where 25 per cent of it may be lost during a single summer by evaporation. The sand or rock originally holding the oil is its best reservoir, because it does not permit evaporation, and it furnishes the maximum yield.

Well owners have apparently not realized the importance of considering the durability of well casing in connection with flooding, yet the decay of the casing is probably the chief cause of the trouble.

A well to which water has had no access for a score or more of years may be suddenly rendered useless by flooding caused by decay or break in the casing. It is more probable that by action of minerals in the water, chiefly iron sulphate, the pipe has been corroded and water allowed to come into the well.

Another source of flooding may be an abandoned or "dry" well—one that does not yield oil or gas, but contains water. The hole may have been drilled into sands that yield oil at some near-by point, and unless the hole is properly plugged before it is abandoned water from it may enter the oil sand, find its way into neighboring wells, and cause great damage.

Where the rock throughout an oil field is widely flooded, as from abandoned wells whose locations even are no longer known, there seems to be no remedy for the flooding, either by pumping or by drilling deeper.

PERMANENT EFFECTS.

The permanence of the effects of flooding may be judged from the results of experiments made by a number of well owners. Mr. L. C. Sands, secretary of the Oil Well Supply Company, attempted over twenty years ago to restore a flooded area at Elizabeth, W. Va. The wells of the locality produced oil before the civil war at the rate of 200 to 300 barrels a day, but when the war began they were abandoned and water accumulated in them. Mr. Sands purchased about 1,000 acres of oil-producing land and attempted to pump the water off the oil sand. The pumping was continued for a long time, but the yield of oil was increased only about a barrel a day, and the experiment was therefore abandoned.

Flooding is a serious matter. Again and again it is caused by the ignorance or carelessness of the drillers that first enter a field, who practically destroy all chance that it will ever be successfully exploited. "Wild-cat drillers" in a new field, who work rapidly and move from one place to another, frequently cause flooding, for they drive many wells that do not yield oil or gas and abandon them without casing off the water or properly plugging the wells. Even the casing may be withdrawn. Later, oil may be found near by and after being pumped for some time begins to show water, which has entered from the hole first drilled and flooded the sands—that is, has partly displaced the gas and oil.

The term "wild-cat driller" is not used here in an odious sense, for the name is applied to one who drills in a locality where oil or gas has not been previously found—that is to say, to a driller engaged in exploration. The only odium attached to the name is caused by the inefficiency or carelessness displayed by some drillers in every locality.

STATE LAWS FOR PREVENTION.

To guard against flooding, several States in which oil and gas are found have passed laws making it an offense to abandon a drill hole without first plugging it with a wooden plug of a specified length, to be driven down by the drilling tools. The wood swells under the influence of the water and presses against the inner surface of the casing, firmly sealing it at the bottom. Most of the laws prescribe the distance above or below the oil sands at which the plug is to be driven.

If water fills the well to a considerable depth it is difficult to lower through it a plug of the required size, hence the plug is made in the form of a hollow cylinder, which is lowered to the well bottom, and a pin or plug is firmly driven into it by the string of tools. Several feet of earth are then thrown on top of the plug to complete the sealing process. If oil and gas are found at several horizons plugs must be inserted below the lowermost and above the uppermost horizon, and if a water-bearing stratum lies between oil and gas bearing strata this must be plugged satisfactorily both at its top and bottom. In addition the top of the well must be closed by a plug.

So far as the writer knows there is no officer whose duty it is to enforce this law, but prosecution is usually begun on the complaint of residents or well owners in the vicinity of a well that is abandoned or is to be abandoned. It is difficult to enforce the law because the evidence of the plugging can consist only of the word of the driller or contractor, and is impossible to discover by direct observation more than the approximate depth at which the plugs were placed or the manner in which they were inserted.

A few of the statutes relating to the plugging of abandoned wells are quoted here, as they show the seriousness with which flooding is viewed.

In Pennsylvania a law passed June 10, 1881 (sec. 1, P. L. 110), prescribes that—

> Whenever any well shall have been put down for the purpose of exploring for any producing oil, upon abandoning or ceasing to operate the same, the owner or operator shall, for the purpose of excluding all fresh water from the oil-bearing rock, and before drawing the casing, fill up the well with sand or rock sediment to the depth of at least 20 feet above the third sand or oil-bearing rock, and drive a round, seasoned, wooden plug at least 2 feet in length, equal in diameter to the diameter of the well below the casing, to a point at least 5 feet below the bottom of the casing, and immediately after the drawing of the casing shall drive a round wooden plug into the well, at the point just below where the lower end of the casing shall have rested, which plug shall be at least 3 feet in length, tapering in form, and to be of the same diameter at the distance of 18 inches from the smaller end as the diameter of the well below the point at which it is to be driven [and] after it has been properly driven, shall fill in on top of same with sand or rock sediment, to the depth of at least 5 feet.

Ohio has statutes equally specific, as follows:

SEC. 306-4. It shall be the duty of the owner of any well drilled for gas or oil and which in drilling shall have passed through any vein of mineral coal, before abandoning, or ceasing to operate such well, and before drawing the casing therefrom to seal the same in the manner following: There shall be driven in such well to a depth of at least 10 feet below the floor of the lowest coal measure a round seasoned wooden plug at least 3 feet in length and equal in diameter to the well at that point, on the top of which plug shall be filled at least 7 feet of sediment or drillings, or cement and sand. Where any gas or oil well passes through any gas or oil bearing rock lying above the coal measures, the owner of said well or his agent shall, upon abandoning or ceasing to operate such well, drive a dry wooden plug not less than 2 feet in length, equal in diameter to the diameter of the hole, to a point as near as possible to the top of the coal vein, on the top of which plug there shall be filled at least 5 feet of sediment or drillings, or cement and sand, as the mine inspector shall direct. In case such well is not plugged as aforesaid within ten days from the abandonment thereof, the chief inspector of mines or a district inspector of mines may cause the well to be plugged, and the costs and expenses of such plugging may be recovered of the person, firm, or corporation whose duty it is to plug the same, in the manner provided for the recovery of penalties by section 303-5 of the Revised Statutes of Ohio.

Indiana well owners are protected by the following statute:

SEC. 651. PLUGGING ABANDONED WELLS. 2. Whenever any well shall have been sunk for the purpose of obtaining natural gas or oil or exploring for the same, and shall have been abandoned or cease to be operated for utilizing the flow of gas or oil therefrom it shall be the duty of any person, firm, or corporation having the custody or control of such well at the time of such abandonment or cessation of use, and also of the owner or owners of the land wherein such well is situated to properly and securely stop and plug the same as follows: If such well has not been "shot" there shall be placed in the bottom of the hole thereof a plug of well-seasoned wood, the diameter of which shall be within one-half inch as great as the hole of such well, extend at least 3 feet above the salt-water level, where salt water has been struck; where no salt water has been struck such plug shall extend at least 3 feet from the bottom of the well. In both cases such wooden plugs shall be thoroughly rammed down and made tight by the use of drilling tools. After such ramming and tightening the hole of such well shall be filled on top of such plug with finely broken stone or sand, which shall be well rammed to a point at least 4 feet above the Trenton limestone, or any other gas or oil bearing rock; on top of this stone or sand there shall be placed another wooden plug at least 5 feet long with diameter as aforesaid, which shall be thoroughly rammed and tightened. In case such well shall have been "shot" the bottom of the hole thereof shall be filled with a proper and sufficient mixture of sand, stone, and dry cement, so as to form a concrete up to a point at least 8 feet above the top of the gas or oil bearing rock or rocks, and on top of this filling shall be placed a wooden plug at least 6 feet long, with diameter as aforesaid, which shall be properly rammed as aforesaid. The casing from the well shall then be pulled or withdrawn therefrom, and immediately thereafter a cast-iron ball 8 inches in diameter shall be dropped into the well and securely rammed into the shale by the driller or owner of the well, after which not less than 1 cubic yard of sand pumping or drilling taken from the well shall be put on top of said iron ball. (R. S., 1897, sec. 7888; R. S., 1901, sec. 7511.)

The following law also makes it possible for others besides the well owner to remedy the defect and recover the cost of the labor and material:

SEC. 653. LIABILITY. Whenever any person or corporation in possession or control of any well in which natural gas or oil has been found shall fail to comply with the provisions of this act, any person or corporation lawfully in possession of lands situated adjacent to or in the vicinity or neighborhood of such well may enter upon the lands upon which such well is situated and take possession of such well from which gas or oil is allowed to escape in violation of the provisions of section 1 of this act, and pack and tube such well and shut in and secure the flow of gas or oil, and maintain a civil action in any court of competent jurisdiction in this State against the owner, lessee, agent, or manager of said well, and each of them jointly and severally, to recover the cost and expense of such tubing and packing, together with attorney's fee and cost of suit. This shall be in addition to the penalties provided by section 3 of this act. (R. S., 1897, sec. 7890; R. S., 1901, sec. 7513.)

CONTAMINATION OF WATER WELLS.

USUAL METHODS OF PREVENTION.

In water wells less care is exercised in packing, plugging, and casing than in oil or gas wells, though the neglect may have serious sanitary results even if it is of less obvious economic importance.

The water in water wells may be contaminated and rendered unfit for use by allowing water from other sources than those yielding desirable supplies to enter the well. If the well is sunk to a water-bearing bed whose water is made unfit for use by a large content of dissolved minerals, the undesirable water may be shut off by plugging the well above the point where such water is encountered, so that only the shallower supplies will be drawn upon. For this purpose it is customary to use a wooden plug, which expands under the action of the water and fits the well tight. Earth is then thrown on the plug and compacted, and when the plug has decayed the earth itself prevents further trouble.

In drilling a well water may be found at several levels, one of which yields unpalatable water, and it is then desirable to separate the different water-bearing beds and determine the source of the undesirable water. By the proper arrangement of pipes, packers, and plugs, each water-bearing bed can be separated from the others and examined, and when the undesirable bed is located water from it can be excluded by casing it off.

EXAMPLES OF CONTAMINATION.

At a number of places in South Carolina water has been obtained by sinking deep wells, uncased below bed rock, into the fissured crystalline rocks that lie below the soil layer. Of these wells L. C. Glenn says[a]:

> The deeply drilled hole has cut across enough such fissures to obtain a large supply of water for the pumps, yet this water is derived not from a great depth nor from a long distance, but from the great body of ground water near the surface and immediately around the well. If the fissures in the solid rock are very numerous, the area supplying the water is an inverted cone whose apex is the lowest point of entry in the bore hole and whose base is a large circular area of the ground-water surface around the well mouth, and only one, two, or three score feet beneath the surface of the town, with its innumerable sources of pollution of every kind. If the well is supplied by only one fissure or by a few fissures, they must be correspondingly large and furnish more direct and easy lines of flow to the well. They may extend almost uninterrupted nearly up to the surface and furnish a direct channel for surface waters to enter the well.
>
> The amount of water that can be pumped from such wells is usually large and analyses made when the well is first completed have shown a good, pure, clear, and usually soft water, well adapted to almost any purpose. But while at first such deep wells may be protected from contamination by the surface-soil layer, which acts as a filter, and the water may be pure and wholesome, yet they are very apt sooner or later to become contaminated. Constant pumping from them soon causes the indrafts supplying the water to open better channels through the fissures and allows more direct ingress of waters from the surface. These channels sooner or later are able to carry surface contamination directly into the well. Such deep wells are therefore at best open to grave suspicion and constantly need careful watching. This need is all the more necessary because of the fancied security given by the very favorable analysis of the water when first used. Such careful watching will usually result in the condemnation and closing of the well in a few years, especially if the town be of considerable size, so that there is furnished to the soil a large amount of contaminating organic material. A well of this kind drilled over 2,000 feet deep in Atlanta, Ga., some years ago, which at first furnished a large amount of acceptable water, was ordered closed by the board of health after a few years' use because of sewage pollution.

Two specific illustrations of the contamination of water wells have been furnished by the late J. E. Bacon, hydrologic engineer, as a result of experiments made to improve the water supply of Saginaw, Mich., and Dallas, Tex.

Previous to 1902 a part of the city supply of Saginaw was drawn from a deep-well system consisting of about 20 bored 4-inch wells, having depths ranging from 89 to 230 feet. These wells, most of which penetrated bed rock, were being contaminated by the infiltration of brine from abandoned salt wells. Up to the time Mr. Bacon began his investigations almost no attempt had been made at Saginaw to protect ground water from contamination of this kind. The seriousness of the situation may be understood from the fact that possible sources of ground-water supply at Saginaw are limited to the loose sands and gravels that overlie the rock and to the upper layers of the rock itself. Manifestly the only way in which this water can

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[a] Underground water of South Carolina: Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 143, 144.

be kept pure is by plugging abandoned salt wells at a suitable distance below the surface and by exercising great care in maintaining the casing of other wells intact. The contamination has been partly remedied and purer water is obtained for municipal purposes from the glacial sands and gravels that overlie the sandstone.

At Dallas, Tex., water is yielded by four geologic formations.[a] One of the city wells penetrates a formation (the third in downward sequence) whose water has a high temperature and is so strongly mineralized as to be extremely unpalatable and unfit for domestic supply, though it is somewhat used for medicinal purposes by a number of the residents of the city. This water is so corrosive that casing that had been in the well only one year showed many breaks and checks, several of them half an inch in diameter. The threads at the casing joints were so completely destroyed that when an attempt was made to pull the casing each length was lifted out as if it had no connection with the piece below. As a tight casing it was practically valueless. As the water in this formation is under greater head than that in the next water bearer above, the sands of the latter were becoming impregnated with the mineral substances contained in the lower water. By inserting a packer in this well between the two formations, with piping to the surface, the two waters were separated, the mineral water coming up inside the pipe and that from the higher formation rising between this pipe and the well casing. Differences in head and in the quality and temperature of the waters were at once noticed. Although the water from the higher beds was at first notably mineralized, the mineral content decreased with continued use.

RESULTS OF DEFECTIVE CASING.

Iron pipe put into the ground in the form of a sewer is not expected to last more than ten to fifteen years, but if it is put into the earth in the form of a well casing it is usually tacitly assumed that it will last indefinitely. That casing suffers deterioration and decay and that it should be examined at intervals for resulting defects is, however, shown conclusively by its condition when it is withdrawn after having been in the earth only a short time.

The life of a casing can not be definitely predicted, the rate of its decay depending on the special conditions in each well. Casing withdrawn from some wells fifteen to twenty years old has been found to be in fairly good condition except at the joints, though as a rule at this age it is too badly corroded to be withdrawn at all.

Decay of the casing may result in admitting to a well, and thus polluting the supply, undesirable water that was originally cased off. Recasing the well then becomes necessary.

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[a] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex.: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1897, pp. 199–321.

In artesian basins where many wells have been sunk the head may be greatly reduced and wells near the border of the basin may even be rendered nonflowing by allowing the wells to discharge continuously. To prevent this needless tax on the underground supply, a number of States have passed laws prohibiting the waste of water from flowing wells and requiring the owners to provide means for closing the wells when the water is not needed. Even where such precautions are taken, however, much water may be lost through defective casing, which allows leakage into shallower porous beds.

RECOMMENDATIONS.

The vital character of the problems involved in water-well pollution should lead to the following definite procedure in sinking important wells:

1. An accurate log of the well should be kept, so that the depth and character of the water-bearing formations may be known.
2. Every water-bearing layer should be carefully examined as to its thickness and the quality of the water it yields.
3. The head of water of each water-bearing layer and its relation to other water encountered should be accurately determined, so that, if necessary, contamination may be prevented by using packers and separate pipes for each water horizon.
4. The casing should be intact when the well is completed, and should be kept so in order that it may fulfill its duty in shutting out undesirable water. Its condition should be determined from time to time by suitable experiments.
5. The possible effects of defective casing should always be considered in interpreting a change in the head or the quality of the water.
6. In those States in which the geological conditions favor contamination of underground-water supplies, the examination of the well casing and the determination of the relations of separate water-bearing beds should be imposed by law on each well owner or well driller.
7. In States where flowing artesian water is obtained, laws should provide for the closing of flowing wells when they are not in use, so that the artesian basins may not be needlessly drained.

CAPACITY OF WELLS.

SIMPLE TESTS.

The testing of the capacity of a water well is the duty of the driller and is considered an essential part of the sinking of a well, especially as tests must occasionally be made while the well is being drilled. Wells sunk by percussion methods may be tested by bailing rapidly with a bailer or sand bucket, the capacity of the bailer and the time during which the test is conducted being known. The larger wells may be tested by means of a centrifugal pump, and many small wells are tested merely by attaching a hand pump and pumping rapidly for several hours.

The proper testing of a well, however, involves also a knowledge and interpretation of the geologic structure as revealed by the boring.

In many parts of New England the rocks consist of schists, gneisses, and granites, and the structure is so complex that conditions are extremely unfavorable for procuring water by deep wells. The water supplies obtained are chiefly from the streams or from the ground water in the decayed upper portion of the crystalline rocks. Some of the drillers and many of the well owners in this region believe that sufficient water may be obtained if only the wells are drilled deep enough. But sometimes a driller who realizes the fallacy of this belief nevertheless fosters the idea in the mind of the owner and drills a well 400 or 500 feet deep into " dry " rock. The surface water drains into it, and the " test " consists in pumping accumulated surface water from a deep drill hole.

A test of this character which was conducted under circumstances that make the naming of the specific locality inadvisable is here cited, because it affords a by no means isolated example and because its mention may prevent a repetition of the trick. The well had been drilled 350 feet deep and the suction pipe was extended nearly to the bottom of the well. The well was tested by a steam pump for ten or fifteen minutes, until the surface water was exhausted, when the driller always found some excuse for stopping the engine. By the time the imaginary difficulty was overcome sufficient surface water had again accumulated in the bore hole to permit steady pumping for several minutes more. The well owner was satisfied with the test and was about to accept the well when his attention was called to the conditions. On insisting that the well be pumped continuously for several hours he discovered the source of the water and its small amount.

TESTS OF FLOWING WELLS.

Other phases of the testing of water wells have been discussed by Chamberlin. In speaking of the defective flow of artesian wells, he says:[a]

> It is possible, in perfect honesty, to make both a negative and a false test. Suppose that two porous beds, A and B [fig. 21], separated by an impervious layer, are traversed, and the testing of the first has been neglected, either because it failed to give encouraging indications or for other reasons. It is now desired to test these. Suppose the seed bag or rubber packing be placed above the upper one. Now, if both bear a water level equally high the test will be fairly made and the result will indicate their combined capacity; or, if both

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[a] Chamberlin, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 160–162.

heads are at least as high as the surface at the well, the test may be accepted. But suppose that the bed A has been cut into by erosion or been reached by crevices or is otherwise defective, while the other, B, remains intact and bears an elevated fountain head. Under these conditions the water may flow from B through the bore into A and escape laterally through it, as illustrated in the figure. Now. in this case the result may be either simply negative [fig. 21] or positively false and misleading [fig. 22]. If the lateral leakage through the stratum A effectually disposed of the flow from B, and there was no leakage in the upper portion of the well, the water in the test tube would stand during the test at essentially the same height as before, and the result would be negative, merely failing to indicate a possibility that really existed. If, on the other hand. there was lateral leakage through the upper strata as well as through A, neither alone being quite competent to dispose of the flow from B, then the introduction of the test pipe would cut off the upper leakage, leaving the bed A unable to dispose of the entire flow. In this case there would be a rise of water in the tube and possibly a flow. The mischievousness of a test of this sort lies in the fact that it appears to be a true test, because it shows some result, while in reality it is false and misleading. The true test in this case can only be made by placing the packing between the porous beds A and B.

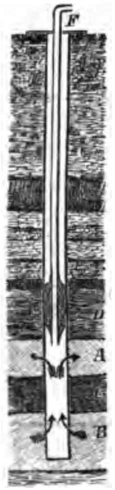

FIGURE 21.—Section of a well illustrating a negative test.

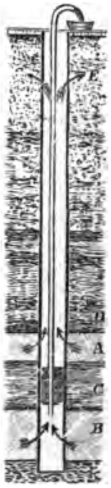

FIGURE 22.—Section of a well illustrating a partial and misleading test.

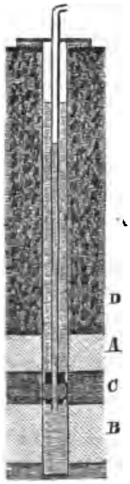

FIGURE 23.—Section of a well illustrating an inverted test.

Take another instance where two porous beds, as A and B, figure 22, have been traversed. Let the packing be placed between these. Then (1), if A equals B in productive capacity, water will stand at the same height within and without the test pipe if there is no leakage in the upper beds. (2) If the failure to flow was due to such leakage, then a flow will result from B, but the additional flow which might be secured from A is lost. (3) If A has a greater head than B, and if there is no loss above, the water in the test pipe will actually be lower than that outside, as illustrated in figure 23. This may be said to be an inverted test and is less misleading than the false and negative tests, since it plainly indicates an error of manipulation. I have known such a case of reduced head as the result of an attempted test. (4) If, however, there is in this case considerable lateral waste in the upper strata, the valuable flow from A will be lost just as before the test was made, while B may give a rise in the tube, or even a flow, which would foster the impression that a fair test had been made, while in reality the greater flow has been lost. (5) If A gives a feebler flow than B, but has an equal head, the test will fail of being completely satisfactory only in excluding the feebler flow from A. (6) If, however, A has a lower head and is a possible means of escape from the flowage from B, then the packing has been placed at the right point and the test gives the best results.

3. In still another case let A and B represent porous beds, the lower of which is so conditioned as to drain the upper one by virtue of a lower outcrop. (1) First, if the drainage loss below is not complete, and if the packing is placed above A, as shown in figure 24, I, the result will be negative if there is no leakage in the upper strata. (2) Should there be considerable loss there it will be cut off by the tube and packing, and some rise in the tube will be the result in most cases. In either instance the result is misleading, particularly in the last, because the small rise of the water is apt to allay any suspicion as to the effectiveness of the test. The real fact, however, remains that the flow from the productive stratum is mainly lost below. (3) Suppose that the packing is located between A and B, as in figure 24, II, it will then shut off the flow from A, while that in B, because of a lower outlet, will fail to flow. Now, if there is opportunity for lateral leakage in the upper strata, the water from A will rise in the well outside of the test pipe and pass off into these open upper beds. (4) But if no such opportunity is afforded it may rise to the surface and overflow outside of the test pipe, while the water within the test pipe will probably be found to be lower than before the test was made. The proper method of testing wells known or suspected to present these conditions is to sink a simple bag of seed or other obstruction to a point in the impervious stratum between A and B, which, when it tightens in its place, will shut off the flow below. Then a tube with packing sunk at a point above A will effectually cut off all leakage in the upper strata, and the full capacity of the water bed A will be tested.

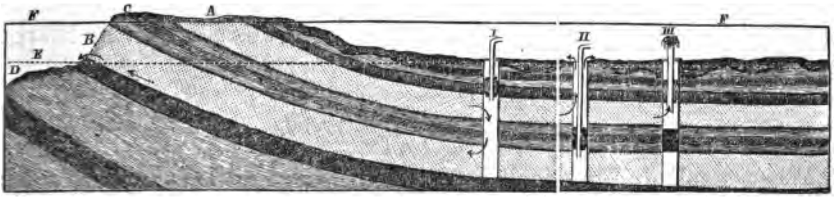

FIGURE 24.—Section of strata showing one correct and two erroneous tests.

These examples, while not exhaustive of possible cases, illustrate the nature of defective tests and the deceptive conclusions liable to be drawn from them. The remedy is manifest. Test each water-bearing stratum as it is encountered, or else vary the final tests so as effectually to exclude all liabilities to error.

STORAGE AND INFLOW CAPACITY.

Water wells drilled to a depth of less than 200 feet are commonly cased with 2-inch pipe, as it is cheap and fairly effective, but it is apt to go crooked or fail to stand the strain of driving to greater depths. Water wells more than 200 feet deep are usually made 5⅝ or 6 inches in diameter. Such wells can be drilled to considerable depths more rapidly than smaller ones, because the tools are heavy and are not so liable to break as are those used in sinking wells of less diameter. The larger pipes also make a larger reservoir for water. Usually sufficient space should be available to hold at least a barrel of water; and if the hole is of small diameter it must be drilled correspondingly deeper, will require more casing, pipe, and pump rod, and involve a heavier lift.

The yield of a well depends on both the size of the hole and the supply. Boring is usually continued some distance below the point where water is tapped, in order to strengthen the supply, and the pump cylinders are placed some distance below the water level to allow for lowering this level by pumping.

The larger well has another advantage where a stratum that yields undesirable water must be cased off. If the well is only 3 or 4 inches in diameter at the top, it is very difficult to continue drilling with a smaller bit after casing off the undesirable water, but if the top diameter is 5⅝ inches it may be easily reduced to 4 inches and the well continued until a desirable water-bearing layer is reached. In most water wells of moderate depth, therefore, except in the matter of original cost, the larger bore is found to be the most economical.

In an oil well the size of the well has immediate bearing on the production of oil, for as the surface of the well wall varies directly with its diameter the production of the well is correspondingly greater with a larger bore. The production of a well often depends also on the size of the charge of nitroglycerin exploded at the level of the oil-bearing sands, and the use of a larger bore allows a heavier charge and insures greater production.

EFFECT OF FRICTION.

When small drilling tools are used the friction, as compared with the impact force of the drill, is greater than when larger tools are employed, for though the frictional surfaces increase directly with the diameter of the drill the proportionate increase in the weight of the drill varies as the square of the diameter. In other words, if the diameter of the drill is doubled the friction surface is also doubled, while the weight or impact force is increased fourfold. For example, if the diameters of two drills are 8 inches and 4 inches, respectively, their friction surfaces, assuming the drills are of equal length, will be in the ratio of 8 to 4, while their volumes or weights will be as 64 to 16. If the larger drill is longer than the smaller one, or if a heavier string of tools is used with the larger drill, the proportionate increase in the impact force will be greater than is indicated above, while the proportionate increase in the friction will remain the same.

Another factor in the friction problem is the steadiness of the drill in the hole. In this respect, also, the large, heavy drill has the advantage, as it is not subject to so great vibration as the small drill, and therefore produces a straighter hole.

MEASUREMENT OF DEPTH.

CABLE MEASUREMENT.

In a well that is being drilled with a standard outfit the depth is usually measured by the cable or derrick method, the distance to the bottom of the well being obtained at any time by measuring the length of drilling cable as the tools are lowered into the hole. Just as the top of the tools are about to enter the hole, a string or a strand of rope is tied to the cable at the bull-wheel shaft. The tools are lowered until this string has gone up over the crown pulley and down to the well head, then another string is tied to the cable at the bull-wheel shaft, and so on until the tools reach the bottom, the last fraction of derrick height being measured by a 5-foot stick. The number of strings tied to the cable is then multiplied by the distance from the bull-wheel shaft up over the crown pulley and down to the well head. This distance, added to the last fraction of derrick height, gives the total depth of the well.

Errors in measurement may be caused by the slipping of the string tied to the cable, by the stretching of the cable, or by miscount of the number of strings. Any one of these inaccuracies vitiates the record for scientific purposes. These errors are, of course, more likely to occur as the well becomes deeper.

TAPE MEASUREMENT.

The exact depth from the surface to the oil-bearing sands is a matter of more importance to the oil-well driller than the exact depth and thickness of each stratum passed through, because it is necessary to avoid error in selecting the position at which to place the torpedo, whose explosion is a matter of great importance in the yield of the well. Therefore, when the oil sands are reached the well is measured by a metal tape. This measurement is a delicate operation, since in some wells one-quarter to one-half mile of tape must be used, the weight of which is considerable, and even in a steel tape the stretch is sufficient to account for many errors of judgment.

The measurement of a well with a steel tape has often been found difficult, on account of the magnetized condition of the well casing, which has been produced by the jarring of the drilling tools and which causes the tape to be drawn to the casing and held there, making a correct measurement impossible. To avoid the difficulties of magnetization a copper wire or tape may be used, as copper does not respond to the magnetic influence of the casing, and by its use a better determination of the depth can be made.

BACON DOUBLE-CONE METHOD.

An ingenious instrument has been devised by Mr. J. E. Bacon for measuring the depth and thickness of water-bearing strata. This instrument is shaped like a double cone, and consists of a central brass plate, over whose edge are drawn wires fastened at each end to a center post. To one end of this apparatus a line is attached. As it is lowered into the hole a steady stream of water under known pressure is forced down the well. This acts on the brass plate and produces a certain determinable tension on the suspending line. When a water-bearing stratum is reached the loss of water into it and consequent decrease of tension on the line as the instrument passes its upper surface at once indicates its position. A reverse change of slighter value as the instrument passes the bottom of the stratum in like manner indicates this second position.

DEFLECTION OF DRILL HOLE.

CAUSES AND RESULTS OF DEFLECTION.

In beginning a well care must be exercised to make the hole perpendicular; otherwise drilling to a considerable depth is very difficult, if not impossible, because of the friction of the tools caused by increasing deflection of the hole. In order to keep the hole straight the driller may lengthen out the tools to 60 or 80 feet, the increase in length being obtained chiefly by using a long auger stem. Notwithstanding this precaution many holes go crooked, especially if the rocks are creviced, or schistose in structure, and the angle of schistosity is only a few degrees from the vertical, for the tools tend to follow the crevices or the structural planes. Under these conditions a hole may not depart greatly from the vertical during the first 1,000 or 1,500 feet, but if this depth is trebled the cumulative result may be remarkable.

Two examples of notable deflection may be cited here. One came under the writer's observation in the summer of 1905 at Casey, Ill., where a water well had been drilled 3 or 4 feet from an oil well, the drilling of which had been delayed at the depth of several hundred feet by lack of water. The driller reported very hard rock at 80 feet, and shortly afterward oil came into the water well. As the rock at that depth contains no oil it was at once suspected that the deflection of the water well had resulted in the drill penetrating the drive pipe of the oil well, and on further examination this was found to be true. The deflection in this well was in the ratio of 1 to 40, and if this had been carried to a depth of 1,000 feet, the deflection of approximately 25 feet would have been so great as to interfere seriously with deeper drilling.

The second example, furnished by a hole in South Africa, is cited in an article by H. F. Marriott.[a] The hole was bored with a diamond drill on the property of the Turf Mines, Ltd., near Johannesburg. As a result of a large number of observations in the vicinity of the property, the average dip of the rocks was taken to be 26° and the strike as due east and west. Instead of going straight down, the hole was deflected northwest from a vertical line and turned more directly toward the north against the strata as sinking progressed. Measurements by an electrical instrument show that the hole was deflected 2,185 feet away from the vertical in a N. 28° W. direction. (See fig. 25.) The actual vertical depth of the bottom of the hole, instead of being 4,802 feet as first recorded, was in realty only 3,910 feet.

These examples indicate the great value if not the absolute necessity of making an accurate survey of deep bore holes; otherwise at depths of 3,000 or 4,000 feet the true position of oil or gas sands or other mineral deposits may not be definitely known.

INSTRUMENTS FOR MEASURING DEFLECTION.

Two styles of instrument have been devised for measuring the deflection of deep holes. One accomplishes this object by means of a compass needle contained in a case filled with a paraffin or other easily melted substance. After being lowered into the hole, the paraffin is melted by means of an electric current, and when sufficient time has elapsed for the needle to assume its proper position, the current is shut off and the paraffin solidifies and holds the needle in position. Errors in using this instrument have resulted from too rapid cooling of the paraffin, and, as the instrument has to be withdrawn for each determination, the process is slow.

In determining the deflection of the South African bore hole previously mentioned, a continuously recording instrument invented by Mr. Marriott was employed. This instrument consists essentially of a strong metallic cylinder containing a resistance coil, commutator, and pivoted switch arm. As the instrument is lowered the varying inclination moves the switch arm over the commutator so as to produce a varying resistance, which is indicated and measured by a galvanometer and resistance box placed at the surface in circuit with the instrument and with several electric cells of known electromotive force. By this means the position of the switch arm on the commutator and hence the inclination of the instrument are determined. Satisfactory check readings are obtained while withdrawing the instrument.

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[a] Marriott, Hugh F., Electrical devices for deep bore hole surveying: Eng. News, July 27, 1905, pp. 91-94.

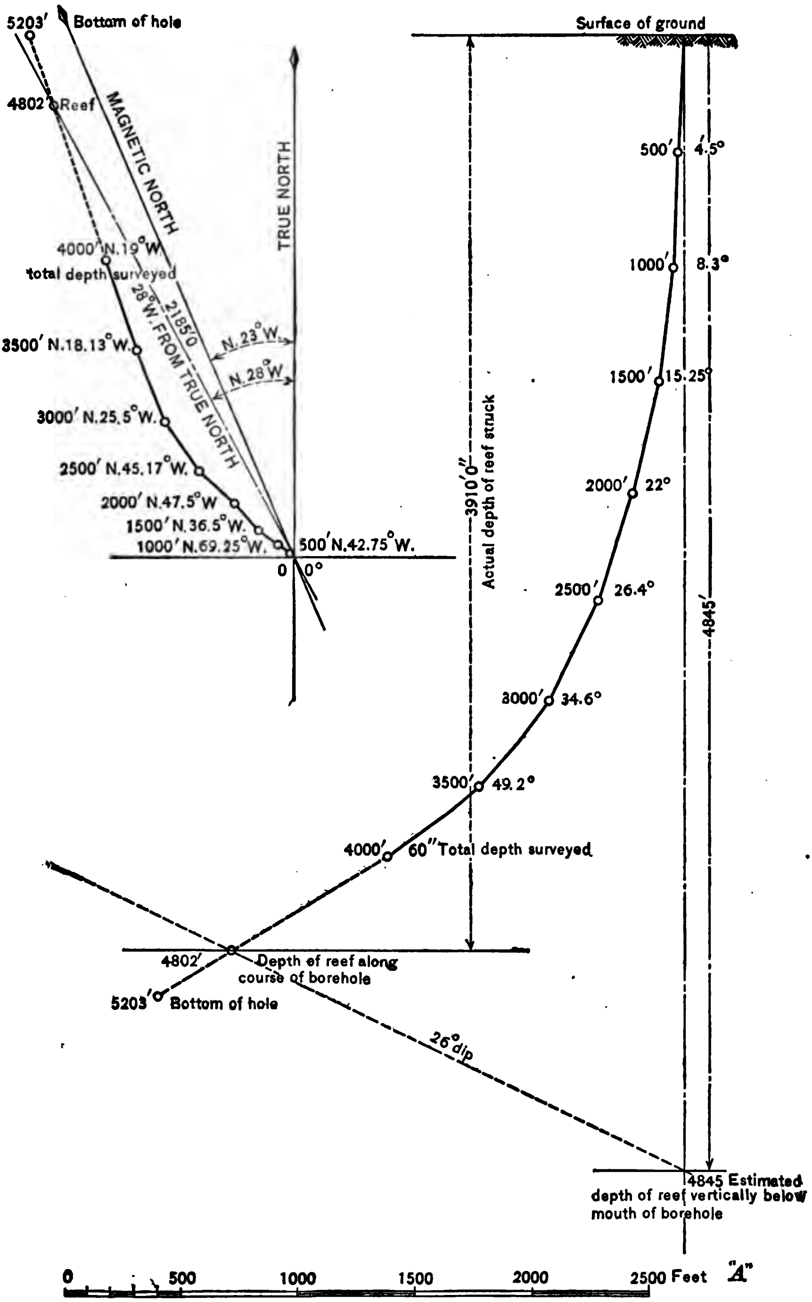

FIGURE 25.—Deflection of a diamond-drill hole in South Africa.

COST OF WELL SINKING.

Factors involved.—No other information connected with well sinking is so hard to obtain or, when obtained, is of so little general value as that relating to cost. In regions where many wells of a particular class have been sunk figures of cost may be fairly reliable; but where underground conditions are not so well known such information is more indefinite and is often withheld by drillers or contractors for business reasons.

The cost of sinking wells is determined chiefly by economic conditions, including cost of labor, material, and transportation; by the size and depth of the well; by the character of the material penetrated; and by the method of drilling employed.

If a well is sunk in a rather inaccessible locality, where fuel is scarce and labor is high, the cost will, of course, be much greater than that of a well sunk by the same method through similar formations in localities where labor and material are cheaper and transportation charges are less.

Increase in diameter of the hole not only increases the cost of sinking because of the additional material that must be removed, but it demands larger and more expensive tools and more power to operate them. The cost of each foot drilled increases rapidly with the depth, for more time is lost in changing the tools and cleaning the hole, and progress is slower because of the decreased speed at which the tools must be operated. Greater labor and ingenuity are also involved in recovering lost tools and overcoming other difficulties.

The rate at which sinking proceeds determines the time required to complete a well, and hence is an important factor in the total cost. The rate of drilling depends both on the material penetrated and the method of sinking employed. Drilling advances much slower in hard, tough rock than in more friable material, and even in plastic clays it is slow, as the material is difficult to penetrate. Quicksands also may cause trouble in some wells. With auger or jetting outfits, however, quicksands can be much more easily and cheaply penetrated than with other outfits.

As the size of the parts and the number of accessory tools for the various rigs depend on the size of the hole to be sunk and the conditions to be met, the figures of cost here presented for the various outfits must be regarded only as approximating the price of the more usual outfits at or near supply points.

Standard method.—The regular standard outfit, including rig, power, and tools, in the Pennsylvania oil fields costs from $1,700 to $3,000 or more. A 72-foot derrick with reels and ironwork costs $600 to $750. The boiler employed varies from 15 to 40 horsepower and the engine from 12 to 30 horsepower, the size depending on the depth to be drilled; the two cost between $600 and $900. The necessary tools usually, cost about $500, though fishing tools and other extras may involve an aggregate expenditure for the outfit of as much as $4,000.

The average cost of oil-well casing ranges from 40 or 50 cents a foot for 4-inch to about $2 a foot for 12-inch, though the price varies with the iron market and with the freight charges.

In the Gaines oil field of northern Pennsylvania, where drilling sometimes proceeds at the rate of 70 feet in twenty-four hours, through shales and shaly sandstones and limestones, drilling is done by contract at about 65 cents a foot, the cost of casing being additional.[a]

In the Coalinga oil district in California, where water has to be purchased and forms an extra item of expense, the average cost of a 4,000-foot well has been estimated at $7,500, divided as follows: Labor and water, $1,500; casing, $2,500; outfit, $3,500.[b] Many of the deep wells in this district, which start with a casing 11⅝ inches in diameter, greatly exceed this average cost, however.

In the Summerland oil district of California wells 6 or 8 inches in diameter at the top and about 250 feet deep are put down at a cost of about 85 cents a foot for drilling only.[c]

Portable rigs.—Portable rigs are much used for drilling water wells 4 or 6 inches in diameter. A machine capable of drilling to a depth of 1,000 feet costs about $1,100 with nontraction power, and about $1,400 with traction power. The tools for such a machine, exclusive of cables, cost $400 to $500 additional. Lighter machines, with a capacity of about 300 feet, cost about $700 with power, this amount being about equally divided between the machine and the engine and boiler. Tools and cable for such a machine cost $200 to $250 more.[d]

The rate of drilling with portable outfits varies. In shale, soft sandstone, and similar materials, 30 to 50 feet a day is a common record; in hard sandstone, 15 to 25 feet a day; and in clay and other unconsolidated material, 75 to 100 feet a day is a fair average.

The cost of drilling wells varies from 10 or 15 cents a foot in the softer materials to $1 or more a foot in hard rock.[e] In the northern Mississippi Valley 4-inch and 6-inch wells in shale and limestone cost 50 cents to $1 a foot for drilling only; in quartzite the cost runs up to $3 and $4 a foot.[f]

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[a] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 605.

[b] Notes of Ralph Arnold, U. S. Geol. Survey.

[c] Bull. U. S. Geol. Survey No. 321, 1907, p. 65.

[d] Net prices given in trade catalogues, 1906.

[e] Statements of drillers.

[f] Water-Supply Paper U. S. Geol. Survey No. 255, 1910, p. 35.

In the hard, tough lava of eastern Washington, where in some wells only 2 or 3 feet a day can be drilled, the drillers charge $2.25 to $3 a foot, fuel and board being furnished them.[a]

The portable rig has been used in drilling shallow holes of small diameter for blasting or exploration purposes at a cost as low as 8 cents a foot.[b]

Pole-tool method.—The figures of cost given above also apply approximately to wells drilled with Canadian pole-tool outfits, for the chief advantage of the use of the pole-tool outfit in some parts of the country is its adaptability to drilling wet holes.

Self-cleaning or hollow-rod method.—Hollow-rod tools are often used with a portable machine built for cable tools, the rods and other extras costing $150 to $250 for a capacity of 250 feet. Additional rods cost 25 cents to $1 a foot, depending on their quality. The common sizes are 1 to 2½ inches in diameter.

Machines built especially for hollow-rod tools, complete with horsepower attachment, tools, and 100 feet of rods, cost from $225 for 2-inch outfits to $325 for 5-inch outfits. The price for a machine with a 5 or 6 horsepower engine and boiler ranges from $650 to $800.[c]

The cost of drilling with hollow-rod tools does not differ greatly from that with small portable cable rigs under similar conditions, but no specific figures are at hand. It is, however, usually 20 to 30 cents a foot, without casing.

California or stovepipe method.—Concerning the California or stovepipe method of well sinking, the following figures have been published. The machinery and power cost $1,500 to $1,800, and the tools and accessories $500 or more, additional; and a pair of hydraulic jacks cost $250.[d] The following tables show approximately the cost of sinking wells by this method and the cost of stovepipe casing. The latter cost, of course, varies with the price of steel.

Cost per foot of drilling wells by the California or stovepipe method.[e]

	4-inch.	5-inch.	6-inch.	7-inch.	8-inch.	9½-inch.	10-inch.
First 100 feet	$0.30	$0.30	$0.35–0.40	$0.40	$0.40–0.50	$0.60–0.65	$0.65
Additional for each 50-foot increase in depth	.25	.25	.20–.30	.20–.35	.20–.35	.20–.35	.35

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[a] Water-Supply Paper U. S. Geol. Survey No. 118, p. 60.

[b] Statements of operators.

[c] Net prices given in trade catalogues.

[d] Stevens Institute Indicator, vol. 22, 1905, pp. 17–30.

[e] Water-Supply Paper U. S. Geol. Survey No. 137, 1905, p. 32.

Cost of riveted steel well casing in 2-foot joints.[a]

Diameter.	Gage.	Price per foot.	Diameter.	Gage.	Price per foot.	Diameter.	Gage	Price per foot.
Inches.			*Inches.*			*Inches.*		
4	16	$0.32	7	16	$0.48	9½	14	$0.75
4	14	.38	7	14	.55	9½	12	.94
5	16	.35	8	16	.55	10	16	.68
5	14	.43	8	14	.64	10	14	.78
6	16	.42	8	12	.78	10	12	.98
6	14	.50	9½	16	.65			

[a] Water-Supply Paper U. S. Geol. Survey No. 137, 1905, p. 32.

At the prices given in the preceding tables a 6-inch well 500 feet deep, with casing, would cost between $750 and $1,000, assuming that the initial diameter is maintained all the way down.

The average rate of sinking wells by this method is 40 to 50 feet in a 10-hour day.

Hydraulic rotary method.—The hydraulic rotary method of drilling, like the standard method, requires heavy machinery, and the cost of outfit is consequently high. In the Beaumont field of Texas the derrick costs about $125, and the machinery, including two boilers and two pumps, costs about $3,600.[a] For wells approximately 3,000 feet deep a 30 to 40 horsepower boiler, 10½ by 12 inch single-cylinder engine, and duplex pumps, with cylinders 10 by 5 by 12 inches, are commonly used.

Water wells 400 to 1,000 feet deep and 6 to 8 inches in diameter have been put down in southern Arkansas with hydraulic rotary outfits for $2.50 to $5 a foot, including casing.[b]

In the Beaumont oil field of Texas the contract rate for sinking by this method has averaged $4 to $4.50 a foot, including casing. In this region it takes about two months to drill a well 800 to 1,000 feet deep.[c]

Jetting method.—No figures are at hand as to the cost of jetting machines, but as the main parts of the outfit are a small derrick and a force pump the apparatus is not expensive.

In southern Arkansas 4-inch wells have been jetted down to a depth of 400 feet at a cost of $1 a foot without casing; in Louisiana smaller wells have been sunk at an average cost of 39 cents a foot.[d] In the Coachella Valley, in southeastern California, 4-inch wells are sunk and cased by contract to depths of 500 and 600 feet for $1 a foot.[e] In the coastal plain of southern California wells 2 to 4 inches in diameter and usually less than 100 feet deep are sunk by this method for 30 to 40 cents a foot, the cost of casing being additional.[f]

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[a] Letters from supply companies.

[b] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 110.

[c] Bull. U. S. Geol. Survey No. 212, 1903, pp. 169–170.

[d] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 108 and 109.

[e] Statements of contractors.

[f] Water-Supply Paper U. S. Geol. Survey No. 137, 1905, p. 32.

Core drills.—Core drills are made in a number of sizes, from hand-power machines of 300-foot capacity to electric or steam driven machines capable of boring to depths of 6,000 feet.

The hand-power drill illustrated in Plate III, *A*, with accessories and 200 feet of rods, is listed at about $600, and the powerful machine shown in Plate III, *B*, with accessories and 2,000 feet of rods, is quoted at approximately $5,500.

In 1906 the market price of carbons was $85 to $90 a carat. Since 8 stones weighing 1 to 4 carats apiece are required for each bit the bits may cost as much as all the rest of the outfit.

The wear on carbons is usually 30 to 80 cents a foot, averaging 30 to 40 cents in moderately hard rock. The total costs of drilling in moderately hard material under ordinary conditions have been $1.50 to $2.50 a foot for holes 1¼ to 1¾ inches in diameter.[a]

Records of rates of drilling show an average in chert and quartz of 75 to 80 feet for a week of sixty hours; in basalt, sandstone, slate, and diabase, about 100 feet; and in limestone 150 to 200 feet.

It is claimed that the cost of drilling with calyx and shot bits is less than that with a diamond bit under the same conditions, and that cores of larger diameter are obtained.

When chilled shot are used, the consumption is one-quarter to three-quarters of a pound for each foot drilled in soft rock, and 1½ to 4 pounds in hard material.[b]

Augers.—Hand augers to be used with common water pipe as extension rods are on the market, and range in price from about $5 for 2-inch augers to $40 or $50 for 10 and 12 inch sizes. Horsepower machines capable of boring wells 100 feet deep and 40 inches in diameter are listed at about $200.

Water wells 3 or 4 inches in diameter can be bored with hand augers at a cost of 25 to 35 cents a foot without casing; wells 6 inches in diameter have been sunk at a cost of about 50 cents a foot.[c] With the Arkansas clay auger, using horsepower, wells are put down at a cost of 12½ to 40 cents a foot.[d]

Driven wells.—The cost of driven wells consists mainly in the outlay for drive point and strainer, pipe, and suction pump. The driving itself does not require expensive machinery nor skilled labor.

A 1½-inch drive point and screen costs about $2.50; 25 feet of 1½-inch pipe, about $3; and a pitcher pump, about $5; so that the cost of small driven wells should not be more than $15.

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[a] Articles in mining journals.

[b] Statements in trade catalogues.

[c] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 109–110.

[d] Op. cit., p. 95.

SUPPLY COMPANIES.

A list of the companies dealing in well-drilling machinery that have furnished information either by catalogue or by correspondence is given below. As there is unfortunately no trade journal devoted to well-drilling machinery and most of the firms handling such machinery do not advertise in the engineering journals a complete list of American firms was not obtained. It is thought, however, that companies handling all the various kinds of well machinery are represented.

List of drill manufacturers and supply companies.

Cook Well Company, St. Louis, Mo.—auger and well screen.

Cyclone Drilling Company, Orrville, Ohio—portable drilling outfits.

Ingersoll-Rand Company, 11 Broadway, New York City—calyx drill.

Keystone Driller Company, Beaver Falls, Pa.—portable drilling outfits.

Loomis Machine Company, Tiffin, Ohio—portable drilling outfits and horsepower and handpower augers.

National Supply Company, Pittsburg, Pa.—standard, hydraulic rotary, and portable oil-well outfits.

Oil Well Supply Company, Pittsburg, Pa.—standard, hydraulic rotary, Canadian pole-tool, and portable oil-well outfits.

Southern Well Works Company, Beaumont, Tex.—standard and hydraulic rotary outfits.

Sullivan Machinery Company, 42 Broadway, New York City, and Railway Exchange Building, Chicago—diamond drills.

American Diamond Drill Company, New York—diamond drills.

American Well Work, Aurora, Ill.

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